Volume 33 SEPTEMBER, 1959 Number 5

Claude W. Hibbard

JOURNAL OF PALEONTOLOGY

A publication of The Society of Economic Paleontologists and Mineralogists *and* The Paleontological Society *with the generous support and cooperation of* The American Association of Petroleum Geologists *and* The Geological Society of America

CONTENTS

Brachiopods of the Lower Devonian rocks at Highlands Mills, New York ..... *Arthur J. Boucot* 727
Early Pennsylvanian fusulinids and ostracods of the Illinois Basin ..... *M. L. Thompson, R. H. Shaver, and E. A. Rigg* 770
Middle Devonian auloporid corals from the Traverse group of Michigan ..... *J. Lloyd Watkins* 793
More Mississippian Belemnites ..... *Rousseau H. Flower and Mackenzie Gordon, Jr.* 809
Occurrence of the foraminiferal species *Acervulina linearis* Hanzawa from St. Bartholomew Island, French West Indies ..... *Shoshiro Hanzawa* 843
A method for rapid sorting of Foraminifera from marine plankton samples ..... *Allan W. H. Bé* 846
A new fossil stingless bee (Meliponini) from the amber of Chiapas, Mexico ..... *Alvaro Wille* 849
A new hemipteran (Dipsocoridae) from the Miocene amber of Chiapas, Mexico ..... *Pedro Wygodzinsky* 853
Paleoecology of a molluscan fauna from the Trent formation ..... *A. Barrett Smith* 855
The Middle Pliocene mammalian fauna from Smiths Valley, Nevada ..... *J. R. MacDonald* 872
Size and shape variation in the brachiopod *Schizophoria* from the Devonian of Western Australia ..... *J. J. Veevers* 888
The type species of *Productella, Emanuella, Crurithyris,* and *Ambocoelia* (Brachiopoda) ..... *J. J. Veevers* 902

SYMPOSIUM ON FIFTY YEARS OF PALEONTOLOGY, PARTS 4-6
A half century of paleontology ..... *Carl O. Dunbar* 909
Vertebrate paleontology, 1908-1958 ..... *Alfred Sherwood Romer* 915
Paleoecology—Retrospect and prospect ..... *Preston E. Cloud, Jr.* 926

PALEONTOLOGICAL NOTES
Reexamination of *Paleocrinus devonica* Clarke ..... *Harry S. Ladd* 963
Leiorhynchus or *Nudirostra* ..... *Paul Sartenaer* 964
First record of Monaxon from the Cretaceous of Santa Barbara de Barinas, Venezuela ..... *G. R. Pierce and S. P. Welles* 966
The reported occurrence of *Keithrodontomys* in the Pleistocene of Florida ..... *Robert S. Bader* 968

NOMENCLATURAL NOTE
Textularia yorktownensis, new name ..... *James D. McLean, Jr.* 969

SOCIETY RECORDS AND ACTIVITIES 969

EDITORS

For The Paleontological Society: ERWIN C. STUMM, Museum of Paleontology, University of Michigan, Ann Arbor, Michigan.

For The Society of Economic Paleontologists and Mineralogists: M. L. THOMPSON and CHARLES COLLINSON, Illinois State Geological Survey, Urbana, Illinois. Associate Editors: Robert H. Shaver, Indiana Geological Survey, and Alan B. Shaw Shell Oil Company.

The JOURNAL OF PALEONTOLOGY is published bimonthly. The issues for January, May, and September are sponsored by The Paleontological Society in cooperation with The Geological Society of America; those for March, July, and November are sponsored by The Society of Economic Paleontologists and Mineralogists in cooperation with The American Association of Petroleum Geologists.

The subscription price for the JOURNAL is $15.00 per year prepaid to addresses in the United States. Postage is charged extra for all other countries in the Postal Union, 40 cents on annual subscriptions (total $15.40). Single numbers $3.00 each to nonmembers, $1.75 to members.

Communications about the JOURNAL, advertising, subscriptions, rates, change of address, and nonreceipt of preceding numbers, should be addressed to The Society of Economic Paleontologists and Mineralogists, P. O. Box 979, Tulsa 1, Oklahoma. Claims for nonreceipt of preceding numbers must be submitted within three months of the date of publication in order to be filled gratis. Communications about membership and requests for blanks for nomination of new members should be directed to the secretary of the respective society.

Authors should consult a recent issue of the JOURNAL for appropriate style and form before preparing their manuscripts. A brief, informative abstract should accompany every article except nomenclatural notes only one or two paragraphs long in which the title is sufficient to serve as an abstract of the contents. All new taxonomic names proposed in a paper should appear in the abstract.

Contributors are requested to instruct their photographers to illuminate fossils from the upper left side, the conventional manner. Plates normally should be arranged for publication at the maximum size of 5½×8½ inches, exclusive of margins and heading. Printed numerals of standard size and form may be obtained free from the editors. When requesting them state number of plates and dimensions of each plate. Text-figures should be designed for reproduction at either single column (2½ inches) or full page (5½ inches) width, maximum height 7½ inches. Typewritten copy is not acceptable for text-figures.

OFFICERS OF THE SOCIETIES

THE SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

For the year ending April 1960

President
SAMUEL P. ELLISON, JR., Austin, Texas

Past-President
GORDON RITTENHOUSE, Houston, Texas

Vice-President
WILLIAM J. PLUMLEY, La Habra, California

Secretary-Treasurer
JOHN IMBRIE, New York, New York

Editors
M. L. THOMPSON AND CHARLES W. COLLINSON
Urbana, Illinois
for Paleontology
JACK L. HOUGH, Urbana, Illinois
for Mineralogy

THE PALEONTOLOGICAL SOCIETY

For the year ending November 1959

President
FRANK M. SWARTZ, University Park, Pa.

Vice-President
WILLIAM R. EVITT, Tulsa, Oklahoma

Secretary
HARRY B. WHITTINGTON, Cambridge, Mass.

Treasurer
CLAUDE C. ALBRITTON, Dallas, Texas

Editors
ERWIN C. STUMM, Ann Arbor, Mich.
ROBERT V. KESLING, Ann Arbor, Mich.

Past-Presidents
ARTHUR K. MILLER, Iowa City, Iowa
G. ARTHUR COOPER, Washington, D. C.
HENRYK B. STENZEL, Houston, Texas

Second-class postage paid at the Post Office at TULSA, OKLAHOMA, and an additional mailing office, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in paragraph 4, section 538, P. L. and R, authorized April 3, 1935.

Printed in U. S. A.

GEORGE BANTA COMPANY, INC., MENASHA, WISCONSIN

5395Z NSF C-5635 C W H.BOARD

JOURNAL OF PALEONTOLOGY

A publication of THE SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS *and* THE PALEONTOLOGICAL SOCIETY *with the generous support and cooperation of* THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS *and* THE GEOLOGICAL SOCIETY OF AMERICA

VOLUME 33 SEPTEMBER, 1959 NUMBER 5

BRACHIOPODS OF THE LOWER DEVONIAN ROCKS AT HIGHLAND MILLS, NEW YORK

ARTHUR J. BOUCOT

Massachusetts Institute of Technology, Cambridge, Mass.

ABSTRACT—A sequence of Lower Devonian rocks at Highland Mills, Orange County, New York, includes (in ascending order) the Central Valley sandstone (new name), the Connelly conglomerate, the Highland Mills member (new name) of the Esopus formation, the middle member of the Esopus formation, the Woodbury Creek member (new name) of the Esopus formation, and the Kanouse sandstone. The Central Valley sandstone is of late Helderberg or Oriskany age, the Connelly conglomerate is of Oriskany age, the Highland Mills member is of post-Oriskany and pre-Woodbury Creek age, the middle member of the Esopus formation is unfossiliferous, the Woodbury Creek member is of post-Highland Mills and pre-Onondaga age, and the Kanouse sandstone is of Onondaga age.

The articulate brachiopod fauna of thirty-nine forms, and two new genera, is described. The fauna of the Highland Mills member is correlated with that occurring in the lower part of the Gaspe sandstone.

Emphasis is placed upon the recognition of stratigraphic breaks by study of the phylogeny of closely related genera present in the beds above and below a suspected break.

The developmentally and stratigraphically intermediate faunas of the Highland Mills and Woodbury Creek members lead to the recognition of an Esopus stage in the Early Devonian of the Appalachians.

INTRODUCTION

RESTUDY of the Lower Devonian faunas from the railroad cut at Highland Mills (text-fig. 1), Orange County, New York (text-fig. 2), first described by Clarke (1909), and of the Lower Devonian faunas from the adjacent roadcut of the New York State Thruway (text-fig. 2) sheds new light on the stratigraphy of eastern New York and adjacent New Jersey.

The fossil collections were loaned for study by Mr. Robert Finks, who showed the Thruway section to the writer. The fossil collections were subsequently donated to the U. S. National Museum by Mr. Finks.

The purpose of this paper is to present additional information regarding the stratigraphic succession, lithology, and brachiopod faunas of the section exposed at Highland Mills, which is located on the eastern side of the Green Pond-Schunemunk Mountain outlier.

ACKNOWLEDGMENTS

I am deeply indebted to Mr. Robert Finks for first pointing out to me the new Thruway cut at Highland Mills, and for the opportunity to study the collections which he generously donated the U.S.N.M. Dr. Donald W. Fisher, State Paleontologist of New

York, and Mr. William Lynn Kriedler, of the New York State Geological Survey, generously made available the results of sections measured at Highland Mills. Professor Cecil Kindle kindly lent collections of brachiopods from the Highland Mills area upon which he had based a previous paper (Kindle & Eidman, 1955, p. 184). Professor H. B. Whittington, Harvard University, very helpfully examined and reported on trilobites from the Central Valley sandstone and the Highland Mills member of the Esopus formation. Dr. Winston Sinclair, Geological Survey of Canada, kindly examined and reported on conularids from the Highland Mills member of the Esopus formation. Photographs of the fossils were made by Mr. Nelson W. Shupe of the U. S. Geological Survey. Lastly, I wish to express special thanks to Dr. G. A. Cooper, who has acted as my preceptor in studying brachiopods at the U. S. National Museum, and without whose guidance and advice this work could not have been successfully prosecuted.

PART I

STRATIGRAPHY

GENERAL STATEMENT

The Green Pond-Schunemunk Mountain outlier of eastern New York and northern New Jersey is a complexly deformed and faulted syncline of Silurian and Devonian strata surrounded on all sides by rocks of pre-Silurian age (Kummel, 1908). The rocks in the outlier belong to an eastern, more clastic facies than the rocks to the west in the Delaware Valley and Helderberg regions of New York, New Jersey, and Pennsylvania.

The stratigraphic succession exposed at Highland Mills, in ascending order, is as follows: Central Valley sandstone, Connelly conglomerate, Highland Mills member of the Esopus formation, middle member of the Esopus formation, Woodbury Creek member of the Esopus formation, and Kanouse sandstone. The rocks assigned to the Connelly conglomerate, Esopus formation, and Kanouse sandstone seem to be in large part identical in lithology to these units in their type areas, and it is inferred that the rocks were once continuous between the type areas and the Highland Mills area.

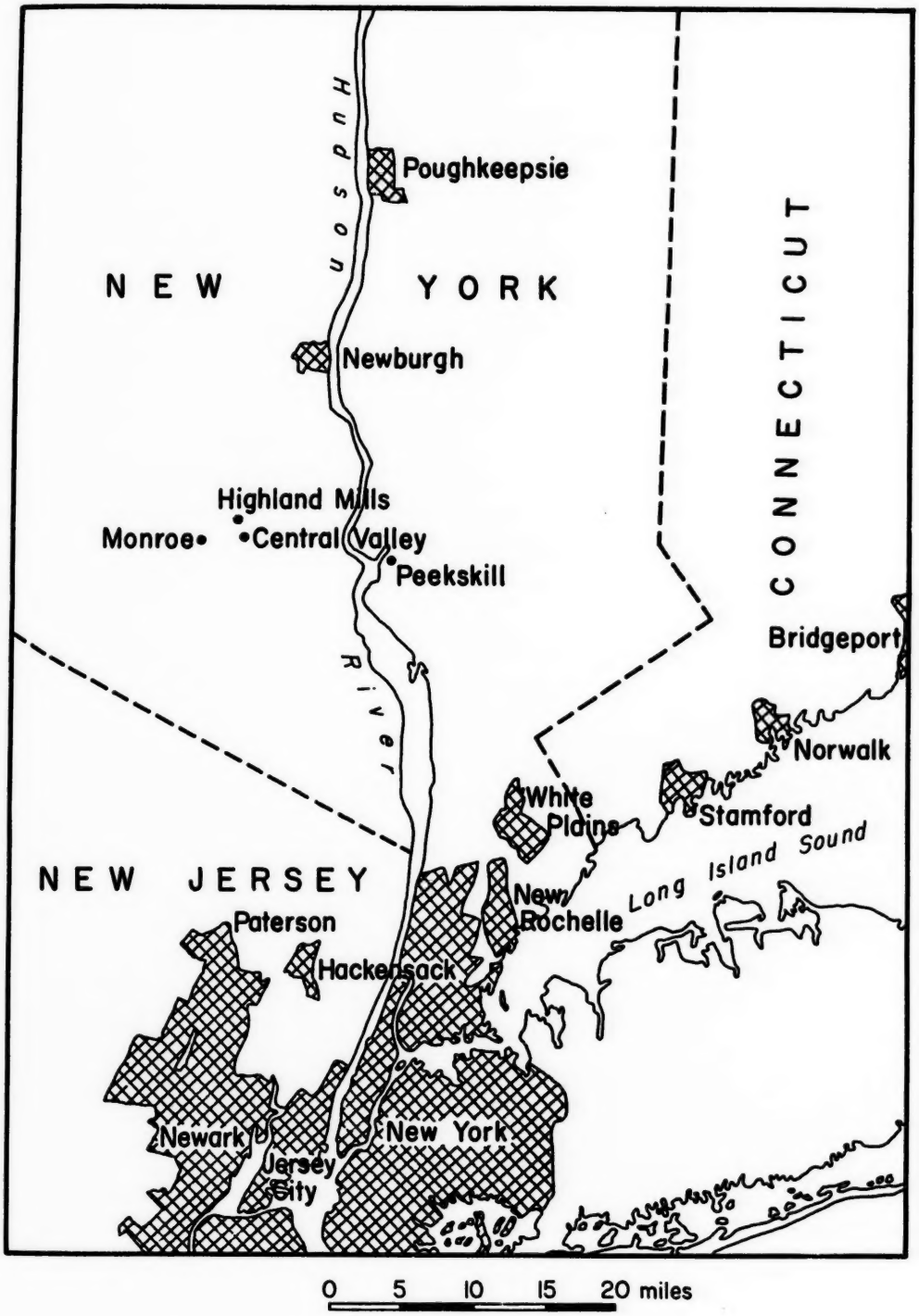
CENTRAL VALLEY SANDSTONE

Name.—The name is taken from nearby Central Valley. The type section is situated in the Thruway cut at Highland Mills. Previous reports of the geology of the Green Pond-Schunemunk Mountain outlier make no mention of quartzose sandstones underneath quartz pebble conglomerate of Oriskany age. Whether this lack of attention is due to absence of the unit elsewhere or to its inconspicuous nature is not clear. The sandstone weathers more easily than the overlying conglomerate, and may, therefore, be represented by a covered interval in most places. It is also possible that previous students of the Green Pond-Schunemunk Mountain outlier have included similar strata with the overlying Connelly conglomerate.

Lithology.—The weathered outcrop on the south end of the west side of the Thruway at Highland Mills consists of white-weathering, mottled violet sandstone with a one-foot bed of white-weathering chert at the top of the unit. The sandstone contains poorly sorted detrital grains of quartz, feldspar, white micaceous minerals, and zircon. The detrital material is of medium-grained sand size and is angular. In addition to the detrital minerals there is a large percentage of white chert. The chert is possibly of secondary origin because the fossils scattered throughout the sandstone and the chert are silicified. The chert bed at the top of the unit may represent a bed that was replaced during weathering rather than primary chert. No information is available as to the time of silicification.

Thickness.—Fisher and Kreidler (written communication, 1956) measured a thickness of 25 plus feet for this unit.

Lower contact.—The lower contact of the Central Valley sandstone is covered. It is not known whether it is underlain by beds of New Scotland age such as are reported at nearby Pine Hill (Darton, 1894, p. 380) or whether it rests directly on strata of pre-New Scotland, Upper Silurian age. Fisher and Kreidler (written communication, 1956) measured a concealed stratigraphic interval of 200 feet $\pm$50 on the Thruway before reaching the red shale and siltstone of the



TEXT-FIG. *1*—Index map.

Longwood shale. In a quarry immediately east of the Thruway the top of the Longwood is exposed. At the quarry the Longwood is directly overlain by about thirty feet of calcareous shale, impure limestone, and banded limestone which Finks (written communication, 1956) compares to the Rondout of the Kingston, N. Y. region. It is, therefore, entirely possible that a complete, but covered, Helderberg section is preserved at Highland Mills.

Upper contact.—The contact with the overlying quartz pebble conglomerate of the Connelly conglomerate is well exposed in the Thruway cut at Highland Mills. The contact is abrupt with no gradation or interbedding of the two rock types. The marked contrast and sharp change in lithology suggest that this is at least a local disconformity, but its time significance is difficult to determine because of the difficulty of precisely dating the Central Valley sandstone.

Remarks.—The presence of Early Devonian sandstone beneath the Connelly conglomerate further emphasizes the change in facies during the Devonian from calcareous strata in the west to arenaceous strata in the east.

Distribution.—The outcrop on the Thruway at Highland Mills is the only known exposure of the Central Valley sandstone.

Age.—The following fossils have been identified in this unit:

Platyorthis planoconvexa
Camarotoechia? sp.
Hysterolites sp.
Meristella? sp.
Cyrtina rostrata
Leptostrophia sp.
Leptaena "rhomboidalis"
Chonetes sp.
Nanothyris cf. *N. subglobosa*
pterineoid pelecypod
cf. *Dipleura* sp.
Odontochile sp.
proetid
unidentified tetracoral

H. B. Whittington (written communication, 1956) identified the trilobites in the above faunal list.

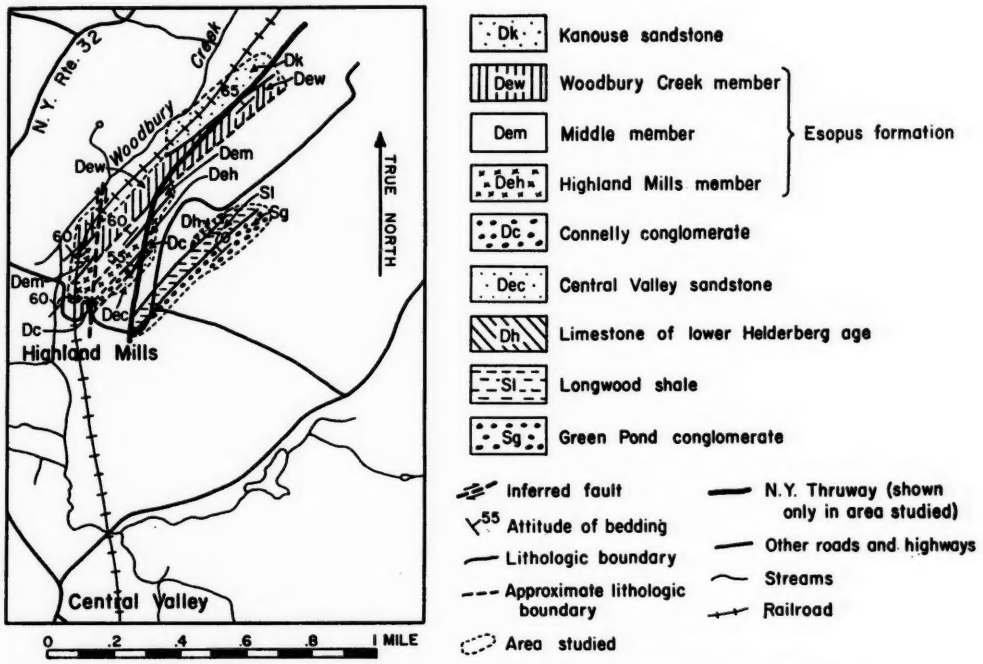
The Central Valley sandstone is of Becraft to Oriskany age, with a suggestion that it may prove to be closer to the Oriskany than to the Becraft.

The occurrence of *Platyorthis*, *Hysterolites*, and *Nanothyris* cf. *N. subglobosa* proves that the sandstone is of Lower Devonian age as these genera are restricted elsewhere to the Early Devonian. *Leptostrophia* has not been reported elsewhere above strata of Oriskany age. The presence of *Hysterolites*, which is known only from beds of Oriskany to Onondaga age, suggests a post-Helderberg assignment. *Hysterolites*, however, may be found to be present in the poorly known faunas of the Alsen or Port Ewen limestones. It probably does not occur in the Becraft limestone as the brachiopod fauna of the Becraft is relatively well known. *Nanothyris* cf. *N. subglobosa* has not been reported above strata of Oriskany age nor below those of Becraft age. The remaining elements of the fauna are long ranging and add nothing to our knowledge of the age of the unit.

CONNELLY CONGLOMERATE

Name.—The term Connelly conglomerate was first used by Chadwick (1908, p. 346–348) for strata which underlie the Glenerie limestone of Oriskany age and overlie the Port Ewen limestone of either Oriskany or late Helderberg age near Connelly Post Office in the Rhinebeck quadrangle, New York. Neither the Port Ewen nor Glenerie limestone is known in the Green Pond-Schunemunk Mountain outlier, but the existence of numerous exposures of conglomerate and quartzite suggests their equivalence with the outcrop of the Connelly conglomerate near by to the southeast. The Oriskany sandstone itself does not occur south of the Coxsackie quadrangle or east of the Hudson River (Grabau, 1903; Goldring, 1943, p. 197), so that the former continuity of the Oriskany sandstone with the beds of equivalent age in the Green Pond-Schunemunk Mountain outlier is doubtful.

Lithology.—From a number of localities in the Green Pond-Schunemunk Mountain outlier Darton (1894, p. 375–378) described strata that he called "Oriskany quartzites": "light-colored quartzite containing quartz grains and pebbles . . . white, light gray or buff quartzite, containing much coarse sand and more or less quartz pebbles . . . white conglomeratic quartzite." However, Darton (*idem*) did not recognize beds of either Esopus or Kanouse lithology in the Green Pond-Schunemunk Mountain outlier. Therefore,



TEXT-FIG. 2—Geologic map of Silurian and Lower Devonian rocks between Erie Railroad and New York Thruway at Highland Mills, New York.

some of the beds assigned by Darton to the Oriskany are probably of Kanouse or Esopus age.

The following description will be based on the well-dated exposure in the Thruway cut at Highland Mills. The rock is a quartz pebble conglomerate, stained reddish-brown by limonite. The pebbles are well-rounded, consist almost entirely of milky quartz, have an average diameter of five to eight millimeters, with a few as large as seven cm. in diameter and associated with well-sorted, medium- to coarse-grained, moderately well-rounded, interstitial sand grains. The rock is silicified, with the contained fossils replaced by chert. The fossils are abraded and often broken, indicating that the sediment was deposited under turbulent conditions. It is not possible to determine whether the siliceous cement and the chert that replace the fossils are of relatively recent origin consequent with weathering or whether they are diagenetic features of the rock. There is a decrease in grain size towards the top of the formation; the upper-most few feet are quartzose sandstone that is almost lacking in pebbles.

Thickness.—Fisher and Kreidler (written communication, 1956) measured a thickness of 45½ feet for this unit.

Upper contact.—The upper contact of the Connelly conglomerate with the overlying Highland Mills member is abrupt. The sharp contact and change in lithology suggests that the contact is a disconformity. The time and areal significance of the contact is not known due to ignorance of the lateral extent of the overlying Highland Mills member of the Esopus formation and to the time interval represented by the disconformity. Fisher and Kreidler (written communication, 1956) noted a limonitic "iron-oxide" zone, up to three inches thick in some places and absent in others, at the upper contact and concluded that a "marked disconformity" is present.

Distribution.—Darton's descriptions (1894, p. 375–378) suggest that the Connelly conglomerate may be present intermittently under rocks that he assigned to the Monroe shale, although some of the exposures asasigned by him to the "Oriskany quartzites" may prove to belong to the younger units

(Kanouse and Esopus) of pre-Hamilton age. Therefore, the Connelly conglomerate appears to have at one time extended from the lower Hudson River Valley near Kingston southwesterly as far as the Green Pond-Schunemunk Mountain outlier.

Age.—The following fossils have been identified in the Connelly conglomerate at Highland Mills:

Costispirifer cf. *C. arenosa*
Meristella? sp.
Hipparionyx cf. *H. proximus*
Rensselaeria cf. *R. elongata*
Beachia sp.

In other parts of New York *Costispirifer*, *Hipparionyx*, and *Beachia* are restricted to strata of Oriskany age. Outside of New York *Hipparionyx* and *Beachia* are also restricted to strata of Oriskany age. Therefore, it is concluded that the beds here assigned to the Connelly conglomerate contain broken and abraded fossils of Oriskany age and probably are of Oriskany age themselves. However, the possibility that the fossils have been eroded from an older formation, not present in this locality, and redeposited here cannot be disproved.

ESOPUS FORMATION

Name.—The term Esopus shale (Darton, 1894B) was introduced to include the *Taonurus*-bearing mudstones of eastern New York. At Highland Mills the *Taonurus*-bearing beds can be subdivided into three parts based on minor changes in lithology. The lower and upper members are faunally distinguishable from each other, but the middle member contains only *Taonurus*. The faunas present in the lower member, here named the Highland Mills member, and the upper member, here named the Woodbury Creek member, have not been recognized elsewhere in the central and southern Appalachians. The fauna of the Highland Mills member is concluded to be a correlative of the York River sandstone, in the lower portion of the Gaspe sandstones.

Elsewhere in New York the Esopus formation has not been subdivided either on a faunal or lithological basis. The Highland Mills occurrence is the first thus far described which suggests that the Esopus represents a relatively long period of time distinct from either the underlying rocks of Oriskany age or the overlying rocks of lower Onondaga (Schoharie) age.

Thickness.—Fisher and Kreidler (written communication, 1956) measured a thickness of about 200 feet for this formation.

HIGHLAND MILLS MEMBER

Name.—The term Highland Mills member is here applied to strata that overlie the Connelly conglomerate and grade up into the middle member of the Esopus formation. The type section is the west side of the Thruway cut at Highland Mills. These beds were referred to by Clarke (1909) as the "Pine Hill Oriskany."

Lithology.—The beds assigned to the Highland Mills member consist of interbedded yellow to gray sandstone and dark-gray shale. The sandstone beds thicken and thin rapidly and are not continuous along strike. Current ripples about an inch in width occur on some bedding planes. Fossils are largely restricted to shell lenses in the sandstone. The sandstone beds range from a few inches to several feet thick, as do the shales with which they are interbedded. The sandstone beds become darker-colored as the percentage of fine-grained material associated with the sand-size grains increases. The sandstones contain about five to ten percent detrital feldspar; the remainder of the sand size grains are mostly quartz with a few percent of platy minerals. A few one-foot beds of red and green shale are present in the lower portion. The sandstone is well indurated and has a non-calcareous, presumably siliceous cement. The sandstones are jointed. The shales are cut by cleavage planes. The basal bed of the formation is a layer of dark bluish-gray paper-thin shale which has abrupt contacts with the Connelly conglomerate below and the sandstone above.

Thickness.—This unit has a thickness of about 50 feet.

Upper contact.—The Highland Mills member has a gradational contact with the overlying mudstones of the middle member. No evidence of disconformity was observed either in the Thruway or in the adjacent railroad cut at Highland Mills.

Distribution.—The Highland Mills member is known definitely only in the vicinity of Highland Mills. However, beds of this

unit are probably present elsewhere in the Green Pond-Schunemunk Mountain outlier but have not been recognized. Darton (1894) may have included the Highland Mills member in the lower part of his Monroe shale (Cornwall shale of Hartnagel, 1907) or in the upper part of the Connelly conglomerate (Darton's "Oriskany quartzites"). No similar fossiliferous strata of this age have been reported from northeastern Pennsylvania, northwestern New Jersey, or the Hudson Valley region of New York.

Age.—The Highland Mills member rests disconformably on the Connelly conglomerate, which contains fossils of Oriskany age. The Highland Mills member is gradationally overlain by the unfossiliferous middle member of the Esopus formation, which in turn is overlain gradationally by the Woodbury Creek member. The lower part of the Woodbury Creek carries a fauna of pre-Onondaga, post-Highland Mills age, and the upper part a fauna of Onondaga age.

The following brachiopods have been identified in the Highland Mills member:

Platyorthis planoconvexa
Camarotoechia? sp.
Leptocoelia flabellites
Hysterolites perimele
Cyrtina rostrata
"Schuchertella" sp.
Eodevonaria cf. *E. gaspensis*
"Chonetes" cf. *"C." nectus*
Etymothyris sp.
Prionothyris diobolaris
Meganterella finksi

H. B. Whittington (written communication, 1956) reports the presence of *"Synphoria"* sp. and a proetid.

On the basis of its intermediate stratigraphic position and transitional fauna, the Highland Mills member is considered to be of post-Oriskany, pre-Woodbury Creek age, and, because of the presence of *Etymothyris*, to be a correlative of the Gaspe sandstone.

Eodevonaria and *"Chonetes"* cf. *"C." nectus* are not known elsewhere below strata of Gaspe sandstone and Onondaga age. *Meganterella* is known only from the Highland Mills member. *Etymothyris* is known elsewhere only from the Gaspe sandstone (Cloud, 1942, p. 59). The Gaspe sandstone is considered by Boucot and Cumming (1953, p. 1397) to be of post-Oriskany and pre-Onondaga age. As discussed later, *Etymothyris* is considered to be intermediate in phylogenetic position between *Rensselaeria* (of Oriskany age) and *Amphigenia* (of Woodbury Creek and Onondaga age). *Eodevonaria* cf. *E. gaspensis* is known elsewhere only from the Gaspe sandstone.

MIDDLE MEMBER

Name.—The term Esopus shale (Darton, 1894B) was introduced to include the *Taonurus*-bearing mudstones of eastern New York. At Highland Mills *Taonurus*-bearing mudstones are gradationally underlain by interl edded sandstone and shale of the Highland Mills member and are overlain gradationally by interbedded siltstone and shale of the Woodbury Creek member. The middle member cf the Esopus formation at Highland Mills differs from the Esopus formation in the type region to the west along the Helderberg escarpment only in being slightly cleaved. The middle member at Highland Mills is well exposed in both railroad and Thruway cuts.

Lithology.—The middle member at Highland Mills consists of irregularly bedded layers of mudstone which average about one-quarter to one-half inch in thickness. The mudstone is black where fresh and weathers dark-brown. *Taonurus* occurs on most bedding planes. The unit is cut by steeply dipping joints.

Thickness.—The unit has a thickness of more than 100 feet at Highland Mills.

Upper contact.—The upper contact of the middle member is gradational with that of the overlying Woodbury Creek member.

Distribution.—The Esopus shale is exposed in eastern New York, northern New Jersey, and eastern Pennsylvania.

Age.—The Esopus formation of the main outcrop belt to the west is difficult to date accurately because it does not contain diagnostic fossils. The evidence afforded by the fossils from the section at Highland Mills provides a more definite determination. The underlying Highland Mills member is of post-Oriskany and pre-Woodbury Creek age. The overlying Woodbury Creek member is of Onondaga and post-Highland Mills age. Therefore it is concluded that the middle member at Highland Mills is of post-Oriskany age and is intermediate in age between the Highland Mills member and the

Woodbury Creek member. It is not known whether the Esopus formation in the outcrop belts to the west along the Helderberg escarpment is of exactly the same age as its lithologic equivalent, the middle member, at Highland Mills.

Correlation.—Due to its almost total lack of diagnostic fossils, the Esopus formation has always presented a problem. Generally the Esopus has been assumed to represent only a very short time interval. Therefore, in the past it has been lumped in a time sense either with the overlying or underlying units. Current practice (Cooper et al., 1942, p. 1758–1759) has been to include it with the Schoharie and coeval portions of the lower Onondaga. The current study has shown, however, that Esopus time probably represents as great a time interval as that represented by the Oriskany or the Schoharie-lower Onondaga.

WOODBURY CREEK MEMBER

Name.—The Woodbury Creek member takes its name from Woodbury Creek, which is adjacent to exposures of the member in the railroad cut at Highland Mills. The type section is comprised of the beds mapped as Woodbury Creek in the Thruway cut at Highland Mills, as shown in figure 2.

Lithology.—The Woodbury Creek member consists of interbedded, brown-weathering, medium to fine-grained sandstone. The rock is blue gray where fresh. The exposures are cut by steeply dipping vertical joints and the beds range from a few inches to a few feet in thickness. The rock contains about 50 to 70 percent angular quartz grains, with a few percent detrital feldspar grains; the remainder is fine-grained dark-colored material.

This member contains may worm burrows normal to the bedding planes; these are several inches long and a few millimeters wide.

Thickness.—The unit has a thickness of about 50 feet.

Upper contact.—The upper contact of this member with the overlying Kanouse sandstone is not exposed, but the strata on either side of the contact are conformable. The Kanouse sandstone at Highland Mills is a coarse, clean-washed sandstone and pebble conglomerate and may rest disconformably upon the relatively dirty, underlying sandstone. However, such a relation cannot be proved.

Distribution.—The Woodbury Creek member is known only from the Highland Mills area.

Age.—The Woodbury Creek member rests gradationally on the middle member of the Esopus and is overlain by the Kanouse sandstone of Onondaga age.

The following brachiopods have been identified in the Woodbury Creek member:

"Spirifer" macrus
Hysterolites? sp.
Elytha fimbriata
Pentagonia unisulcata
Cyrtina rostrata
Leptaena "rhomboidalis"
Schuchertella sp.
Eodevonaria cf. *E. arcuata*
Chonostrophia sp.
Anoplia nucleata
Amphigenia preparva
Etymothyris sp.
Amphigenia cf. *A. elongata*

"Spirifer" macrus, *Eodevonaria arcuata*, *Pentagonia unisulcata*, and *Amphigenia elongata* are thus far known only from beds of Onondaga age. The occurrence of *Etymothyris* sp. in the lower half of the member allies it closely to the Highland Mills member, whereas the occurrence of *Amphigenia* cf. *A. elongata* in the upper half allies that portion closely to the Kanouse sandstone of Onondaga age. However, in the lower half of the member there is a new species of *Amphigenia* (*A. preparva*) which is intermediate morphologically between *Etymothyris* and *A. elongata*. *Etymothyris* occurs in the Highland Mills member and the lower part of the Woodbury Creek member; the Onondagan species *A. elongata* occurs in the upper part of the Woodbury Creek. The occurrence of the intermediate form. *A. preparva* in the lower half of the Woodbury Creek member suggests that those beds are of pre-Onondaga and post-Highland Mills age. The upper half of the member is concluded to be of Onondaga age.

KANOUSE SANDSTONE

Name.—The term Kanouse sandstone was first introduced by Kummel (1908) for sandstone and pebble beds of Onondaga age. His usage is followed in this paper.

Lithology.—The Kanouse sandstone at Highland Mills consists of white-weathering, relatively massive exposures of limonite-stained coarse sandstone and pebble beds. The grains are moderately well-rounded but poorly sorted. Fossils are scattered throughout the unit.

Thickness.—A minimum thickness of 50 feet is present at Highland Mills.

Upper contact.—The upper contact with the overlying Cornwall shale, of Hamilton age, is not exposed at Highland Mills, but the similar attitude of beds on either side of the contact suggests that the two units are conformable.

Distribution.—The Kanouse sandstone is known only from the Green Pond outlier.

Age.—The Kanouse sandstone contains a large fauna unquestionably of Onondaga age. The following brachiopods have been recognized from the exposure in the woods between the Thruway and the railroad near Highland Mills:

Rhipidomella musculosa var. *solaris*
Platyorthis planoconvexa
Camarotoechia? sp.
Atrypa reticularis
Acrospirifer macrothyris
"Spirifer" macrus
Elytha fimbriata
Meristella nasuta
Protoleptostrophia sp.
Leptaena "rhomboidalis"
Stropheodonta demissa
Megastrophia hemispherica
Schuchertella sp.
Eodevonaria arcuata
Amphigenia elongata
"Prionothyris" sp.
Centronella sp.

The presence of *Amphigenia elongata* and *Eodevonaria arcuata* is presumptive evidence for an Onondaga age.

THE IDENTIFICATION OF STRATIGRAPHIC BREAKS, AND RELATIONSHIPS BETWEEN THE BRACHIOPOD FAUNAS OF ORISKANY AND ONONDAGA AGE IN EASTERN NORTH AMERICA

In the Appalachian region faunas of Oriskany age are usually succeeded by faunas of Onondaga age, except in those localities where the relatively unfossiliferous Esopus formation intervenes. However, taxonomic study of the brachiopods from the Highland Mills and Woodbury Creek members of the Esopus formation showed that these two faunas were intermediate in type between faunas of Oriskany age and those of Onondaga age. Three possibilities were considered: (1) the Highland Mills and Woodbury Creek faunas were intermediate in age between the Oriskany and the Onondaga, (2) they represented an Oriskany fauna which included precursors of an Onondaga fauna, or (3) they represented an Onondaga fauna which included holdovers from an Oriskany fauna.

A tabulation was made of the brachiopod genera known in eastern North America to be restricted to strata either of Onondaga or Oriskany age, those common to strata of both Oriskany and Onondaga age, those found in beds of Oriskany and older age, those found in beds of Onondaga and younger age, and those ranging both above and below beds of Oriskany and Onondaga age. The results of this tabulation are given below:

Brachiopod genera restricted to strata of Oriskany age:

Plicoplasia
Hipparionyx
Beachia
Eurythyris
Plethorhynchia
Pegmarhynchia
Oriskania

Brachiopod genera restricted to strata of Onondaga age:

Amphigenia
Eodevonaria
Charionella

Brachiopod genera restricted to strata of pre-Onondaga age:

Rensselaeria
"Chonostrophia" (of the *complanata* type)
Nanothyris
Eatonia
Leptostrophia
Mutationella
Howellella

Brachiopod genera restricted to strata of post-Oriskany age:

Pentagonia
Chonostrophia
Spinulicosta
Fimbrispirifer
Paraspirifer
Brevispirifer
Pentamerella

Strophalosia
Camarospira
Eunella
"Spirifer" macrus group

Brachiopod genera restricted to strata of Oriskany and Onondaga age:

Costispirifer
Prionothyris
Metaplasia
Anoplia
Acrospirifer
Hysterolites

Brachiopod genera restricted to strata of post-Helderberg age:

Protoleptostrophia
Elytha
Centronella
Megastrophia
Parazyga

Brachiopod genera restricted to strata of pre-Hamilton age:

Coelospira
Kozlowskiellina
Rhipidomelloides
Costellirostra
Protomegastrophia

Brachiopod genera known both above and below strata of Onondaga age:

Atrypa
Leptaena
Cyrtina
Schuchertella
Meristella
Stropheodonta
Strophonella
Nucleospira
Camarotoechia
Isorthis
Schizophoria
Sphaerirhynchia
Pholidostrophia
Douvillina
Trematospira

The tabulation shows the presence of 25 relatively long-ranging genera common to strata of both Oriskany and Onondaga age, 5 being unknown below strata of Oriskany age, 5 unknown above strata of Onondaga age, and 15 known both above and below strata of Oriskany and Onondaga age. In addition, 6 genera are common only to strata of Oriskany and Onondaga age. Three genera are restricted to strata of Onondaga age, and 11 are of Onondaga age or younger. Seven genera are restricted to strata of Oriskany age, and another 7 are of Oriskany age or older.

Twenty-five relatively long ranging genera may be dismissed from further consideration of the age relations of strata of Oriskany and Onondaga age. Among the remaining genera 6 are common to strata of Oriskany and Onondaga age, whereas 28 are restricted to either beds of Oriskany age and older or Onondaga age and younger. Some of the genera known in strata of Oriskany or Onondaga age but not in both may be exotic elements, introduced from elsewhere in post-Oriskany time and having no possible antecedents locally, whereas others in beds of Oriskany age may be end members of groups which died out or migrated elsewhere at the end of Oriskany time. Still others may be genera which migrated in or evolved from long ranging stocks and first became differentiated in Onondaga time.

There remains a residue of genera appearing to be related at the family or subfamily level and occurring in strata of Oriskany and Onondaga age. These possess morphologic differences which suggest that one genus would not be capable of having directly given rise to another genus, but rather that an intermediate form, not known in the Appalachian region was the more immediate progenitor of the younger genus. The absence of such intermediate forms suggests a gap in the stratigraphic record representing the time during which these intermediate forms were evolving and giving rise to the later form. *Rensselaeria* and *Amphigenia*, *"Chonostrophia"* and *Chonostrophia*, *Meristella* and *Pentagonia*, *Meristella* and *Camarospira* are pairs of closely related genera for which the logical intermediate forms have not previously been found in strata of either Oriskany or Onondaga age.

Recognition that the upper and lower members of the Esopus formation at Highland Mills were fossiliferous immediately raised the prospect of finding some of the presumed intermediate forms that had hitherto never been recognized elsewhere. Unfortunately, meristellids and chonostrophids are exceedingly rare in the Esopus formation at Highland Mills. However, terebratuloids, though not abundant, are evenly distributed throughout the section except in the unfossilferous middle member. It is the critical terebratuloids belonging to the *Rensselaeria-Amphigenia* sequence

upon which the conclusions regarding the intermediate age of the Highland Mills member and the lower half of the Woodbury Creek member are based. The bulk of the lower Woodbury Creek fauna has more affinities with the Kanouse, whereas the Highland Mills has similar affinities with strata of Oriskany age. Ordinarily they would be concluded to be respectively of Oriskany and Onondaga age.

The *Rensselaeria-Amphigenia* Lineage

In the most recent critical review of the Devonian[1] terebratuloids Cloud (1942, p. 77) considered that *Amphigenia* is characterized by "a prominent spondylium duplex, borne on a median septum." A well preserved specimen (Pl. 101, fig. 10) from the Onondaga limestone of New York shows that *Amphigenia* is instead characterized by dental plates which converge basally to form a spondylium supported by a septum formed from their basally conjunct portions. Septae with this type of construction have not previously been noted in association with spondylia, but because the spondylium of *Amphigenia* is a completely parallel, analogous structure to that present in other brachiopod orders it is not unexpected to find a completely different type of construction. An additional and previously unnoted character unique to the spondylium of *Amphigenia* is the presence in the umbonal cavities of a pair of small supporting struts, the mystrochial plates (Pl. 100, fig. 10; text-figs. 3,4). Cloud (1942, p. 38) concluded that the *Etymothyris*-bearing portions of the Gaspe limestone and Gaspe sandstone were of Oriskany and lower Onondaga age respectively. On the basis of the present study, however, the beds in Gaspe that contain *Etymothyris* are concluded to be of Highland Mills age.

The morphology of the spondylium and median septum in *Amphigenia* having been determined, it was possible to recognize the ascending terebratuloid sequence *Rensselaeria-Etymothyris-Amphigenia* (Text-fig. 5) at Highland Mills. The internal morphology of the pedicle valve, in particular the configuration of the dental lamellae, was critical in recognizing this lineage. *Rensselaria*, itself derived from the more generalized form *Nanothyris* as previously deduced by Cloud (1942, p. 55) is characterized in the large specimen by short, almost obsolete dental lamellae postero-laterally bounding the deeply impressed muscle field. *Etymothyris* is characterized by relatively long dental lamellae which also laterally bound a deeply impressed muscle field. In *Amphigenia* the long dental lamellae are basally conjunct and support a spondylium. The spondylium of Onondaga age species of *Amphigenia* is relatively short, as contrasted with the relatively long, anteriorly projecting median septum. A considerable gap clearly existed between *Etymothyris*, with its long, subparallel dental lamellae extending to the anterior edge of the muscle field, and the Onondaga species of *Amphigenia*, in which the spondylium-borne muscle field is situated well posterior of the anterior extremity of the medially joined dental lamellae. It was suspected that an intermediate form characterized by a spondylium discretum, i.e. medially conjunct dental lamellae unsupported by a septum formed from medially conjunct dental lamellae, should exist. Such a structure was found in the species *Amphigenia preparva*, from the lower half of the Woodbury Creek. *Amphigenia preparva* is essentially an etymothyrid in which the dental lamellae meet medially on the floor of the valve, but the presence of mystrochial plates (Pl. 100, figs. 5–7) proves that it more properly belongs to *Amphigenia* than to *Etymothyris*. In other words, the determining character in the differentiation of *Amphigenia* and *Etymorthyris* is not so much the presence of a spondylium as it is the presence of mystrochial plates.

It is to be hoped that when further fossils from the Esopus formation are studied, additional lineages will be found to confirm further the evidence from Highland Mills.

THE ESOPUS STAGE

In the past the stratigraphic significance of the Esopus has been obscure because of the paucity of diagnostic fossils in it. It has been customary to conclude that the Esopus of adjacent New York and Pennsylvania is

[1] Boucot (1957, p. 1702) considers the terebratuloid-bearing portions of the Keyser and Manlius limestones to be of Devonian rather than Silurian age.

TABLE 1—STRATIGRAPHIC DISTRIBUTION OF BRACHIOPODS FROM THE LOWER DEVONIAN ROCKS AT HIGHLAND MILLS, ORANGE COUNTY, NEW YORK

Fossil	Horizon				
	Central Valley Sandstone	Connelly Conglomerate	Esopus Formation		Kanouse Sandstone
			Highland Mills Member	Woodbury Creek Member	
Rhipidomella musculosa var. *solaris*					×
Platyorthis planoconvexa	×		×		×
Camarotoechia? sp.	×		×		×
Atrypa reticularis					×
Leptocoelia flabellites			×	×	
Acrospirifer macrothyris					×
Hysterolites perimele			×		
"*Spirifer*" *macrus*				×	×
Hysterolites sp.	×				
Hysterolites? sp.				×	
Costispirifer cf. *C. arenosa*		×			
Elytha fimbriata				×	×
Meristella? sp.	×	×			
Meristella nasuta					×
Pentagonia unisulcata				×	
Cyrtina rostrata	×		×	×	
Leptostrophia sp.	×				
Protoleptostrophia sp.					×
Leptaena "*rhomboidalis*"	×			×	
Strophеodonta demissa					×
Megastrophia hemispherica					×
"*Schuchertella*" sp. A			×	×	
"*Schuchertella*" sp. B					×
Hipparionyx cf. *H. proximus*		×			
Eodevonaria cf. *E. gaspensis*			×		
Eodevonaria arcuata				×	×
"*Chonetes*" cf. "*C.*" *nectus*			×		
Chonostrophia sp.				×	
Chonetes sp.	×				
Anoplia nucleata				×	
Nanothyris cf. *N. subglobosa*	×				
Rensselaeria cf. *R. elongata*		×			
Etymothyris sp.			×	×	
Amphigenia elongata					×
Amphigenia preparva				×	
Prionothyris diobolaris			×		
"*Prionothyris*" sp.					×
Beachia sp.		×			
Meganterella finksi			×		
Centronella sp.					×

either of upper Deerpark (=Oriskany) or lower Onesquethaw (=Schoharie) age (Cooper, et al., 1942, p. 1758–1759). The discovery of the Highland Mills and Woodbury Creek member faunas makes it clear that Esopus time, if one is to judge by the nature and diversity of the fauna, is of the same order as either Deerpark or Onesquethaw time. Therefore, it is proposed that an Esopus stage be recognized in eastern North America. In eastern New York and Pennsylvania this stage will be represented by the relatively unfossiliferous Esopus formation. Elsewhere in the eastern United States strata of this age are absent, due to disconformity between strata of Oriskany and Onondaga age. The York River sandstone (=lower marine portion of the Gaspe sandstone) contains an *Etymothyris*-bearing fauna similar to that in the underlying up-

permost part of the Gaspe limestones (limestone No. 8) and is correlated with the Highland Mills member of the Esopus formation at Highland Mills. The almost complete absence of Esopus age strata in eastern North America is puzzling until the widespread break beneath strata of Onondaga age is taken into account. The writer and Dr. Ely Mencher, who are preparing an account of the stratigraphic relationships found immediately beneath Onondaga age strata in North America, find a profound disconformity at this horizon almost everywhere except in eastern New York and adjacent Pennsylvania.

STRATIGRAPHIC CONCLUSIONS

The Central Valley sandstone beneath the Connelly conglomerate may be either of high Helderberg or Oriskany age; in any event, it is a clastic unit not present to the west.

Rocks of Oriskany age are represented by the Connelly conglomerate alone, which is separated both above and below by possible disconformities.

The Highland Mills member of the Esopus formation, which overlies the Connelly conglomerate, contains a fauna intermediate in age between those of Oriskany and Woodbury Creek age. The Highland Mills member is correlated with the Gaspe sandstone and represents both a fauna and a rock unit which are not present to the west.

The overlying middle member of the Esopus formation is similar, including lack of diagnostic fossils, to the Esopus formation to the west.

The Woodbury Creek member of the Esopus formation which overlies the middle member is of post-Highland Mills, pre-Onondaga, and Onondaga age. It has no lithologic counterpart to the west.

The Kanouse sandstone is a coarse- to medium-grained, clastic equivalent of the Onondaga limestone and Schoharie grit to the west.

The absence of the Central Valley sandstone, Connelly conglomerate, Highland Mills member, middle member, and Woodbury Creek member in the southern part of the Green Pond outlier (Kummel, 1908) suggests the presence of a major unconformity at the base of the Kanouse sandstone in this region.

PART II

SYSTEMATIC PALEONTOLOGY

Phylum BRACHIOPODA
Class ARTICULATA
Superfamily DALMANELLACEA
Family RHIPIDOMELLIDAE
Genus PLATYORTHIS Schuchert and Cooper, 1931

PLATYORTHIS PLANOCONVEXA (Hall, 1859)
Pl. 90, figs. 3–10

Exterior.—Subcircular in outline, with the brachial valve flat, the pedicle valve convex. Ornamentation consists of fine costellae and concentric growth lines. The hinge line is very narrow, and the anterior commissure is finely crenulate and rectimarginate. The interarea is very limited in lateral extent and is gently anacline. The delthyrium is unmodified by plates of any sort.

Pedicle interior.—Long dental plates diverge laterally at an angle of about 40 degrees and support the stout hinge teeth. The dental plates border the well impressed muscle field. The muscle field consists of a flabellate diductor field, divided medially by a slender myophragm; the diductor impressions enclose the small, elliptical adductor impressions, which are located posteriorly. The anterior margin is crenulated by a series of bifurcating crenulations. The external ornamentation is not impressed on interior of the valve.

Brachial interior.—The cardinalia consist of a stout, erect cardinal process which is anteriorly cleft and posteriorly somewhat bilobed. Lateral of the cardinal process are divergent brachiophores which taper to points and are supported by brachiophore plates. The brachiophore plates are continued anteriorly to surround part of the impression of the muscle field. Dental sockets are formed from the posterior face of the interarea and the lateral face of the brachiophore plates. The muscle field is divided by a broad, low median septum which continues posteriorly to join the cardinal process. The muscle field consists of quadripartite adductor impressions, the anterior pair of impressions being the larger. The anterior margin exhibits bifurcating crenulations.

Occurrence.—Highland Mills, Orange County, New York.

Geologic location.—Central Valley sandstone, Highland Mills member of the Esopus formation, and Kanouse sandstone.

Distribution.—Western Europe and eastern North America.

Figured specimens.—U.S.N.M. 126650–126652, 125890, 125890 A–C.

Unfigured specimens.—U.S.N.M. 125867, 125894.

Genus RHIPIDOMELLOIDES Boucot and Amsden, 1958

RHIPIDOMELLOIDES MUSCULOSA (Hall) SOLARIS (Clarke, 1907)

Pl. 90 figs. 1,2

Remarks.—The Kanouse sandstone has yielded rhipidomellids which Kindle (1955, p. 184) has identified as *Rhipidomella musculosa* var. *solaris*. The peripheral crenulations are flat, rather than rounded as in true *Rhipidomella*. These shells are probably identical with those that Weller (1903, p. 374) identified as "*Schizophoria* sp. cf. *S. striatula* (Schl.)."

Exterior.—The shells are subcircular to transversely elliptical in outline, with maximum width slightly anterior to the midlength. The interarea is about half the maximum width. The hinge line is straight. The interarea of the pedicle valve is short, incurved, and gently apsacline. The interarea of the brachial valve is very short—about one-third the length of the pedicle interarea—and orthocline. The pedicle valve is flat to gently convex, the brachial valve strongly convex. The lateral and anterior commissures are evenly rounded. The pedicle valve in large specimens bears a short, broad anterior sulcus. The anterior commissure is uniplicate and crenulate. The fine ornamentation consists of radial costellae and concentric growth lamellae. The shell is punctate. The delthyrial margins are unmodified.

Pedicle interior.—Short hinge teeth border the delthyrium and project upwards from the inner margins of the interarea. The hinge teeth are basally supported by short dental lamellae. At the base of the dental lamellae a low lateral ridge continues antero-laterally to a point near the midlength and then turns antero-medially, almost surrounding the muscle field. The area of muscle attachment is large, subcircular to transversely elliptical in outline, and usually reaches three-quarters of the distance to the anterior margin. The anterior half of the muscle field is bisected by a low, sharp median septum. Large flabellate diductor impressions surround the small, elongate, posteriorly situated adductor impressions, and are radially divided by a series of short septae. The posterior face of the delthyrial cavity is occupied by the pedicle callist, which is located on a slightly raised pad of secondary material. In large specimens the umbonal cavities are largely filled with secondary material. The anterior and lateral periphery is crenulated by flat crenulae grooved on their upper faces.

Brachial interior.—The cardinalia consists of an erect cardinal process which swells distally, has a trifid posterior face, and is joined postero-laterally with blade-like brachiophores. The brachiophores are supported by brachiophore plates that form the outer face of the dental sockets. Extending anteriorly from the base of the cardinal process is a broad, low median septum which bisects the adductor impressions. The 4 adductor impressions are transversely divided by a pair of low myophragms and extend anteriorly to a position short of the midlength. The anterior and lateral margins are crenulated by flat crenulae which may be grooved on their upper faces.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Kanouse sandstone.

Distribution.—Green Pond-Schunemunk Mountain outlier; northern New Hampshire; northern Maine.

Figured specimens.—U.S.N.M. No. 126748–126749.

Superfamily RHYNCHONELLACEA
Family CAMAROTOECHIDAE
Subfamily CAMAROTOECHIINAE
Genus CAMAROTOECHIA Hall and Clarke, 1893

CAMAROTOECHIA? sp.

Pl. 90 figs. 11–17

Exterior.—Subequally biconvex, with the brachial valve bearing a fold and the pedicle valve a deep sulcus. The fold and sulcus bear 3 to 4 costae, the flanks 5 to 7. The anterior commissure is uniplicate and cren-

ulate. The outline is pentagonal, the interareas being very reduced. Poor preservation of the specimens makes further remarks about the exterior difficult.

Pedicle interior.—Subparallel dental plates laterally enclose the posterior portion of the muscle field and support the hinge teeth. The smooth, undivided impression of the muscle field merges anteriorly with the crenulated internal impression of the external ornamentation.

Brachial interior.—The cardinalia consist of a small cruralium supported by a median septum that extends anteriorly about one-third the length of the shell. The nature of the dental sockets could not be determined.

Remarks.—These rhynchonellids probably belong to *Camarotoechia*, but it could not be determined whether or not the dental sockets were crenulate.

Occurrence.—Highland Mills, Orange County, New York

Geologic location.—Central Valley sandstone, Highland Mills member of the Esopus formation, Kanouse sandstone.

Distribution.—Worldwide.

Figured specimens.—U.S.N.M. 126653, 125891, 125891A.

Superfamily ATRYPACEA
Family LEPTOCOELIDAE
Genus LEPTOCOELIA Hall, 1859
LEPTOCOELIA FLABELLITES (Conrad, 1841)
Pl. 91, figs. 1–6

Exterior.—The brachial valve is relatively flat, the pedicle valve evenly convex. The brachial valve bears a low anterior fold in large specimens, but no anterior fold in small specimens. The pedicle valve bears a low sulcus anteriorly in large specimens, corresponding to the fold on the brachial valve. The outline of the valves is subcircular; the anterior commissure is uniplicate and crenulate. The interareas are very short. The beak of the pedicle valve is suberect. The hinge line is short and curved anteriorly. The delthyrium and notothyrium are unmodified. Ornamentation consists of about 5 plications on either side of the fold and sulcus. The fold bears 2 plications, the sulcus 1 plication. The plications on either side of the sulcus are larger than those on the flanks of the pedicle valve. Pronounced growth lines occur on some specimens, particularly in the brachial valve. The greatest width is about one-fifth of the distance from the posterior of the pedicle valve.

Pedicle interior.—Stout hinge teeth, elliptical in cross-section occur on either side of the flabellate muscle field, near the posterior portion of the delthyrial cavity. A pedicle callist is moderately well developed at the rear of the delthyrial cavity. The muscle field consists of a flabellate diductor field, which extends anteriorly about two-thirds the length of the shell and encloses paired, small adductor impressions which are deeply impressed and lozenge-shaped in outline. The muscle field is medially divided by a myophragm.

Brachial interior.—The cardinalia consists of a sessile cardinal plate surmounted by a boss-like cardinal process. The dental sockets narrow medially to a point and diverge at an angle of about 45 degrees from the midline. The adductor muscle impressions are very pronounced; they are medially divided by a low septum which dies out anteriorly and merges posteriorly with the cardinal plate. The blade-like brachiophores diverge from the midline at an angle of about 45 degrees. Both brachial and pedicle interiors bear the impress of the external plications very prominently around the anterior portions of the shell.

Occurrence.—Highland Mills, Orange County, New York.

Geologic location.—Highland Mills member and lower half of Woodbury Creek member of Esopus formation.

Distribution.—Eastern North America in beds of late Early Devonian and earliest Middle Devonian age (Oriskany and Marcellus).

Figured specimens.—U.S.N.M. 126654–126657.

Unfigured specimens.—U.S.N.M. 125895.

Family ATRYPIDAE
Subfamily ATRYPINAE
Genus ATRYPA Dalman, 1828
ATRYPA "RETICULARIS" (Linnaeus, 1767)
Pl. 91, figs. 7–9

Remarks.—A few specimens of *A. "reticularis"* occur in the Kanouse sandstone. Nothing about the material is unusual, although the absence of the species in the un-

derlying beds lacks an adequate explanation.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Kanouse sandstone.

Figured specimens.—U.S.N.M. 126744, 126744A.

Superfamily SPIRIFERACEA
Family SPIRIFERIDAE
Subfamily HYSTEROLITINAE
Genus HYSTEROLITES Schlotheim, 1820
HYSTEROLITES PERIMELE (Clarke, 1907)
Pl. 92, figs. 6–10

Spirifer perimele Clarke, 1907, p. 253–254.
Spirifer aroostookensis Clarke, 1909 *non* Clarke, 1907, p. 143–144, pl. 34, figs. 6–16.

Exterior.—Shells unequally biconvex, with the pedicle valve the deeper; outline subcircular to elliptical. The shells possess a well-developed fold and sulcus; the fold has a low circular cross-section. Eight to fifteen lateral costellae, rounded in cross-section, are present, and the medial costellae usually bifurcate anteriorly. The pedicle interarea is concave, gently apsacline to orthocline; the brachial interarea is orthocline to anacline. The nature of the deltidial plates is not known. The notothyrium is unmodified. The anterior commissure is uniplicate and crenulate. The fine ornamentation consists of fine spines that project free over the edge of each growth lamella. The interspaces between the lateral costellae are relatively narrow.

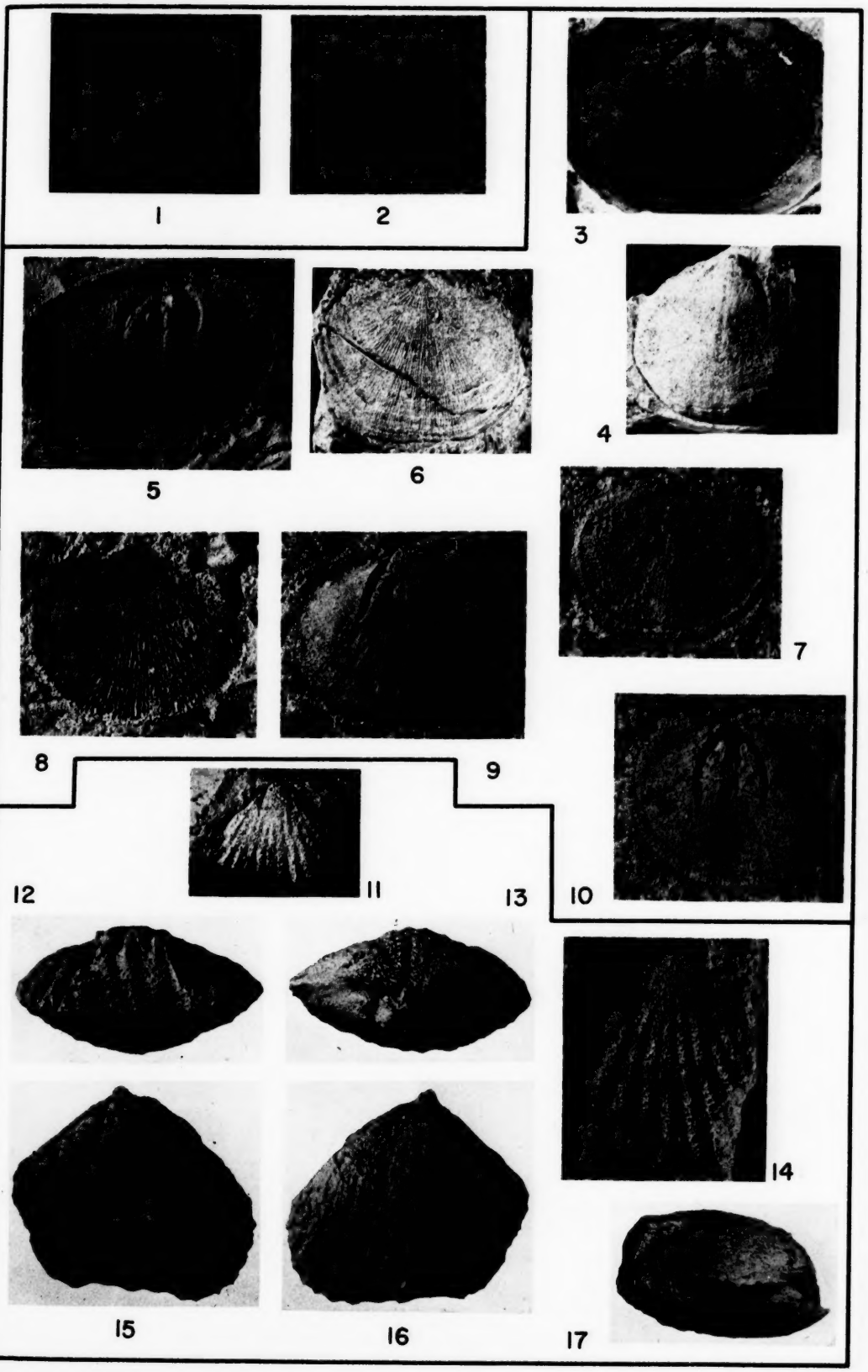
Pedicle interior.—Short, stout dental plates support the stubby hinge teeth and laterally enclose the weakly to moderately well impressed muscle field. The impression of the muscle field projects posteriorly well behind the hinge line. The dental lamellae become increasingly obsolete as shell size increases. The impression of the external costellae is pronounced, and about one less costella is present on the internal impression. The muscle impression in large specimens may be somewhat rugose. A myophragm bisects the muscle field.

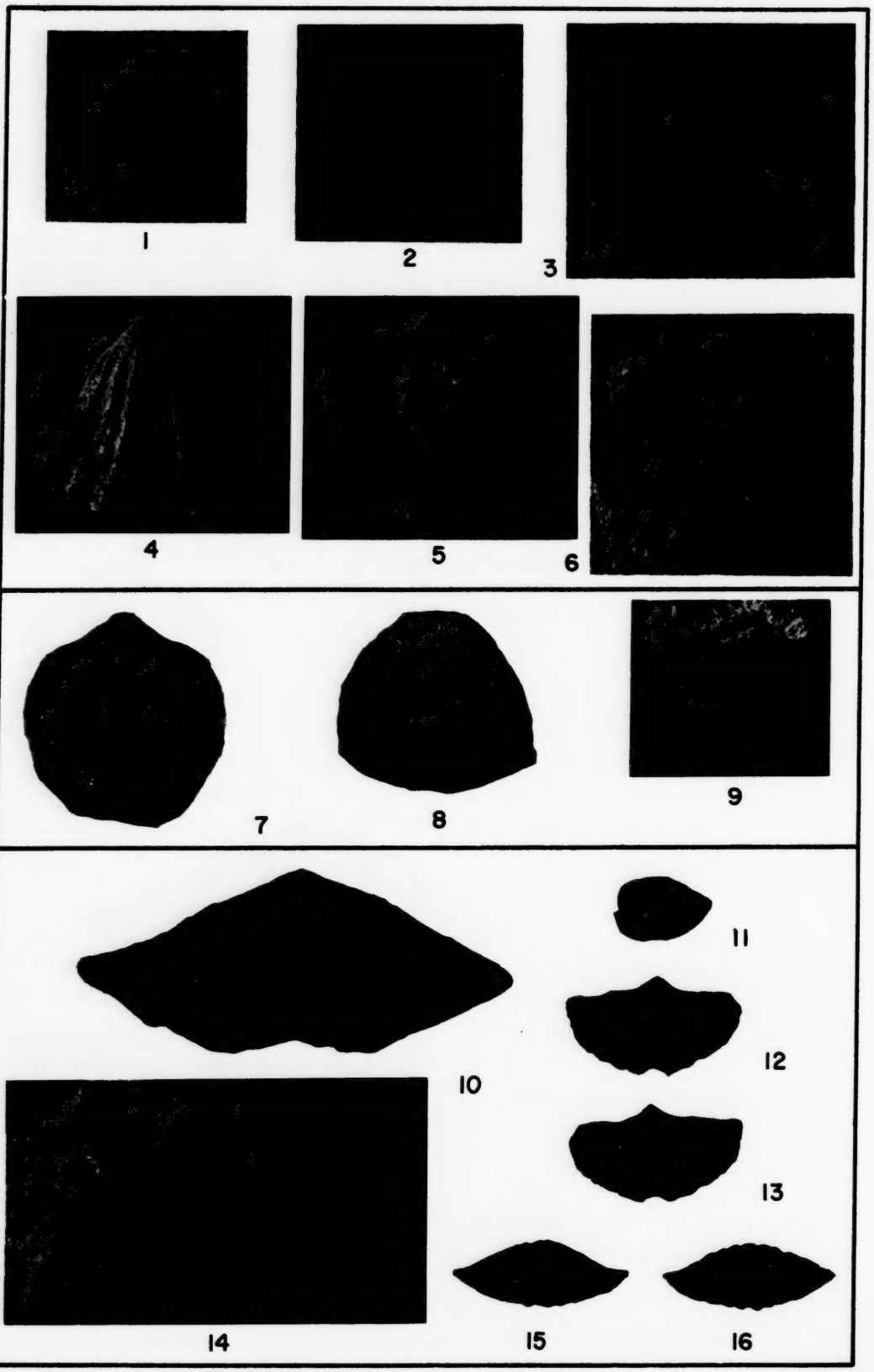
EXPLANATION OF PLATE 90

FIGS. *1,2*—*Rhipidomelloides musculosa* (Hall) *solaris* (Clarke, 1907). *1*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126748; *2*, Impression of interior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126749.

3–10—*Platyorthis planoconvexa* (Hall, 1859). *3*, Impression of interior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 125890-B; *4*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 125890A; *5*, Impression of interior of brachial valve (×2). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126652; *6*, Impression of exterior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 125890-C; *7*, Impression of exterior of brachial valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York, U.S.N.M. No. 126651; *8*, Impression of exterior of pedicle valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York, U.S.N.M. No. 126650; *9*, Impression of interior pf pedicle valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126650; *10*, Impression of interior of brachial valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126651.

11–17—*Camarotoechia?* sp. *11*, Impression of interior of pedicle valve (×2). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 125891A; *12*, Impression of interior (anterior view ×3). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 125891; *13*, Impression of interior (posterior view ×3). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 125891; *14*, Impression of interior of pedicle valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126653; *15*, Impression of interior of pedicle valve (×3). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 125891; *16*, Impression of interior of brachial valve (×3). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 125891; *17*, Impression of interior (side view ×3). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 125891.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Brachial interior.—The cardinalia consist of a ctenophoridium, located at the posterior portion of the notothyrial cavity, and discrete hinge plates whose posterior faces form one side of the dental sockets. The impression of the exterior plications is pronounced; about one less lateral plication is present on the interior than is seen on the exterior. A myophragm bisects the weakly impressed muscle field.

Comparison.—*H. perimele* appears to be conspecific with the material from Highland Mills, New York, that Clarke (1909, p. 143–144) assigned to *Spirifer aroostookensis*. "*Spirifer*" *aroostookensis* Clarke, 1907, is too poorly known to be compared with *H. perimele*, only one fragmentary specimen (which probably belongs to "*Spirifer*" *concinnus* Hall, 1857) being extant.

Occurrence.—Somerset County, Maine; Highland Mills, Orange County, New York.

Geologic location.—Upper part of the Moose River sandstone, and the Highland Mills member of the Esopus formation.

Distribution.—Eastern New York and Northern Maine.

Figured specimens.—U.S.N.M. 126660–126664.

Unfigured specimens.—U.S.N.M. 125896.

HYSTEROLITES MACROTHYRIS (Hall, 1857)
Pl. 91, figs. 10–16; pl. 92, figs. 4,5

Exterior.—The values are subequally convex, with an evenly convex brachial valve and a deeply convex pedicle valve. The shells are subcircular to laterally elongate in outline. The maximum width is near the straight hinge line or about one-quarter of the distance from the hinge line to the anterior margin. The lateral and anterior margins are evenly rounded. The brachial valve bears a broad fold which has a rounded cross-section and the pedicle valve has a corresponding sulcus. The flanks are plicated by 6 to 10 lateral plications which have rounded cross-sections and are separated from each other by U-shaped interspaces. The inter-

---

EXPLANATION OF PLATE 91

FIGS. *1–6*—*Leptocoelia flabellites* (Conrad, 1841). *1*, Impression of interior of pedicle valve (×2.) Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York, U.S.N.M. No. 126657; *2*, Impression of interior of brachial valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126656; *3*, Impression of exterior of pedicle valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126655; *4*, Impression of interior of pedicle valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126654; *5*, Impression of interior of brachial valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126654; *6*, Impression of exterior of brachial valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126655.

7–9—*Atrypa "reticularis"* (Linnaeus, 1767). *7*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126744; *8*, Impression of interior (posterior view ×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126744; *9*, Impression of interior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126744A.

10–16—*Acrospirifer macrothyris* (Hall, 1857). *10*, Impression of interior (posterior view ×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126747; *11*, Impression of interior (side view ×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126745; *12*, Impression of interior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126745; *13*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126745; *14*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126746; *15*, Impression of Interior (posterior view ×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126745; *16*, Impression of interior (anterior view ×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126745.

area of the pedicle valve is relatively short and apsacline, with an incurved beak. The interarea of the pedicle valve is at least 5 times the length of the brachial valve's interarea. The delthyrium includes an angle of about 90 degrees; modifying plates have not been observed. The anterior commissure is uniplicate and crenulate. The fine ornamentation consists of fine radial striations which terminate over the margins of the concentric growth lamellae as a fringe of minute spines. However, the fine ornamentation is seldom preserved in the material from Highland Mills due to a combination of coarse sand matrix and abrasion prior to final deposition of the shells. The number of lateral plications is a function of the size of the shells, additional plications being added laterally with increase in size.

Brachial interior.—The cardinalia consist of a striated area for diductor attachment flanked laterally by discrete hinge plates. The hinge plates are curved to form laterally-directed dental sockets. A low myophragm indents the posterior half of the valve, but the muscle field is not impressed. The interior is crenulated by the impress of the external coarse ornamentation.

Pedicle interior.—The short dental lamellae are almost obsolete due to the deposition of secondary material in the umbonal cavities. The dental lamellae support the stubby hinge teeth which laterally bound the sides of the delthyrium. The muscle field is deeply impressed and extends anteriorly about one-third of the distance to the anterior margin. The muscle field is subcircular in outline and divided into two halves by the sulcus. The lateral portions of the muscle filed are grooved by furrows which are subparallel to the hinge line. The lateral portions of the muscle field project posteriorly as a pair of pointed chambers into the secondary material filling the delthyrial cavity. A diamond-shaped pad of secondary material is situated on the postero-median face of the delthyrial cavity. The interior is crenulated by the impress of the external ornamentation.

Comparison.—*H. macrothyris* is very similar to *H. atlanticus* (Clarke, 1906), but adequate comparative material is not available for formal comparison. It is probable that "*Spirifer*" *duodenarius* Hall represents young specimens of *H. macrothyris*, but again adequate comparative material is not available.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Kanouse sandstone.

Figured specimens.—U.S.N.M. 126745-126747, 126747A–B.

Unfigured specimens.—U.S.N.M. 125921.

HYSTEROLITES sp.
Pl. 92, figs. 2,3

Remarks.—A few fragmentary specimens from the Central Valley sandstone possess the characters of *Hysterolites*, but they are too poorly preserved to be specifically identified. Crural plates are absent in the brachial valve and the median fold is low, rounded, and relatively wide as compared with the lateral costellae.

Occurrence.—Highland Mills, Orange County, N.Y.

Geologic location.—Central Valley sandstone.

Figured specimens.—U.S.N.M. 126658–126659.

Unfigured specimens.—U.S.N.M. 125897.

HYSTEROLITES? sp.
Pl. 92, fig. 1

Exterior.—The single brachial valve collected is laterally elongate and elliptical in outline. The greatest width is at the hinge line, which is straight. The interarea is relatively short and anacline. The lateral and anterior margins are gently rounded. The median fold is relatively narrow and has a high, rounded cross-section. The lateral costellae are rounded and separated by rounded interspaces. The anterior commissure is uniplicate and crenulate. The fine ornamentation consists of radial striae which terminate as a fringe of spines over the anterior margin of each growth lamella. About ten costellae occur on each side of the fold.

Brachial interior.—The cardinalia consist of a ctenophoridium located on the posterior wall of the notothyrial cavity and laterally flanked by hinge plates that curve distally away from the floor of the valve. Whether the baso-median portions of the hinge plates are supported by secondary material or by very short plates could not be determined in this specimen. A low myo-

phragm bisects the muscle field, which is indistinctly impressed. The myophragm extends about one-third of the distance to the anterior margin. The interior is strongly crenulated by the impress of the external ornamentation.

Remarks.—It is not clear from this specimen whether the hinge plates have basal supporting plates or secondary material supporting them. The generic assigment, therefore, is not certain.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Woodbury Creek member of Esopus formation.

Figured specimen.—U.S.N.M. 126736.

Subfamily MUCROSPIRIFERINAE
"SPIRIFER" MACRA (Hall, 1857)
Pl. 93, figs. 1–10

Exterior.—The shell is biconvex, the brachial valve being gently convex and the pedicle valve strongly convex. The shells are laterally elongated and have an elliptical outline. The greatest width is at the hinge line, which is straight. The lateral margins are concave anteriorly in the region of the ears, gently convex anteriorly in a more medial direction. The anterior margin is gently rounded. The brachial valve bears a narrow, low fold with a subrectangular cross-section, and the pedicle valve has a corresponding sulcus. The coarse ornamentation consists of rounded costellae separated by rounded interspaces. Each valve has from about 12 to 17 lateral costellae, the valves with greater width possessing more costellae than the narrower specimens. The interarea of the brachial valve is short and anacline; that of the pedicle valve is steeply apsacline and relatively long. The delthyrium appears to be open and includes an angle of about 60 degrees. The anterior commissure is uniplicate and strongly crenulate. The fine ornamentation consists of radial striae which terminate as a fringe of minute spines over the anterior edge of each growth lamella.

Pedicle interior.—Short, stubby hinge teeth are situated on the inner margin of the hinge line and are supported by short dental lamellae. The dental lamellae are almost entirely obsolete due to the deposition of secondary material in the umbonal cavities. The muscle field is well impressed into the secondary material that lines the posterior portion of the valve. The muscle field consists of paired, elongate lateral diductor impressions which laterally and anteriorly enclose the small, narrow adductor impressions. A triangular pedicle callist impression is located on the posterior wall of the delthyrial cavity. Each dental lamella is indented by a step which probably served to seat deltidial plates that were subnormal to the interarea. The umbonal region is pustulose, and the peripheral regions are strongly crenulated by the impress of the external ornamentation.

Brachial interior.—The cardinalia consist of a small ctenophoridium located in the posterior part of the notothyrial cavity and laterally flanked by hinge plates, which curve distally away from the floor of the valve and posteriorly form the anterior walls of the dental sockets. The impression of the muscle field is not visible. The interior is strongly crenulated by the impress of the external ornamentation.

Remarks.—The specimens from Highland Mills are similar in form to those from the Onondaga limestone.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Woodbury Creek member of Esopus formation and Kanouse sandstone.

Distribution.—Eastern United States southwest of New England.

Figured specimens.—U.S.N.M. 126732–126735, 126735A–C.

Unfigured specimens.—U.S.N.M. 125924.

Subfamily ELYTHINAE
Genus ELYTHA Fredericks, 1918
ELYTHA FIMBRIATA (Conrad, 1842)
Pl. 93, figs. 14–16

Remarks.—Both the Woodbury Creek member of the Esopus formation and the Kanouse contain spiriferoids possessing double-barrelled spines fringing each growth lamella, this being the key character of the members of the Elythinae. The form and ornamentation of these specimens are similar to that of *E. fimbriata*.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Woodbury Creek mem-

ber of Esopus formation and the Kanouse sandstone.

Figured specimens.—U.S.N.M. 126739–126740, 126740A.

Subfamily COSTISPIRIFERINAE
Genus COSTISPIRIFER Cooper, 1942
COSTISPIRIFER sp. cf. C. ARENOSUS (Conrad, 1839)
Pl. 93, figs. 11–13

Remarks.—A few silicified pedicle valves obtained from the Connelly conglomerate possess the typical flat, bifurcating costellae and costellate sulcus that characterize *Costispirifer*. The specimens have short dental plates supporting stubby hinge teeth, as well as a deeply impressed muscle field. The material is too poor to be specifically identified with certainty but does resemble *Costispirifer arenosus* most closely.

Occurrence.—Thruway cut at Highland Mills, Orange County, New York.

Geologic location.—Connelly conglomerate.

Distribution.—North America.

Figured specimens.—U.S.N.M. 126737–126738.

Superfamily ROSTROSPIRACEA
Family MERISTELLIDAE
Genus MERISTELLA Hall, 1860
MERISTELLA sp.
Pl. 94, figs. 1–4,11

Remarks.—A few poorly preserved shells from the Central Valley sandstone and the Connelly conglomerate possess some of the characters of *Meristella*, but the material is too poor to be identified with certainty.

Occurrence.—Highland Mills, Orange County, New York.

Geologic location.—Central Valley sandstone, Connelly conglomerate.

Figured specimens.—U.S.N.M. 126665–126667.

MERISTELLA NASUTA (Conrad, 1840)
Pl. 94, figs. 5–8,12

Exterior.—The shells are subequally biconvex, the pedicle valve having a slightly greater degree of convexity than the brachial. The shells are subcircular in outline. The cardinal margins of the pedicle valve are terebratuloid in form. The lateral and anterior margins are evenly rounded. The brachial valve bears a low fold which origi-

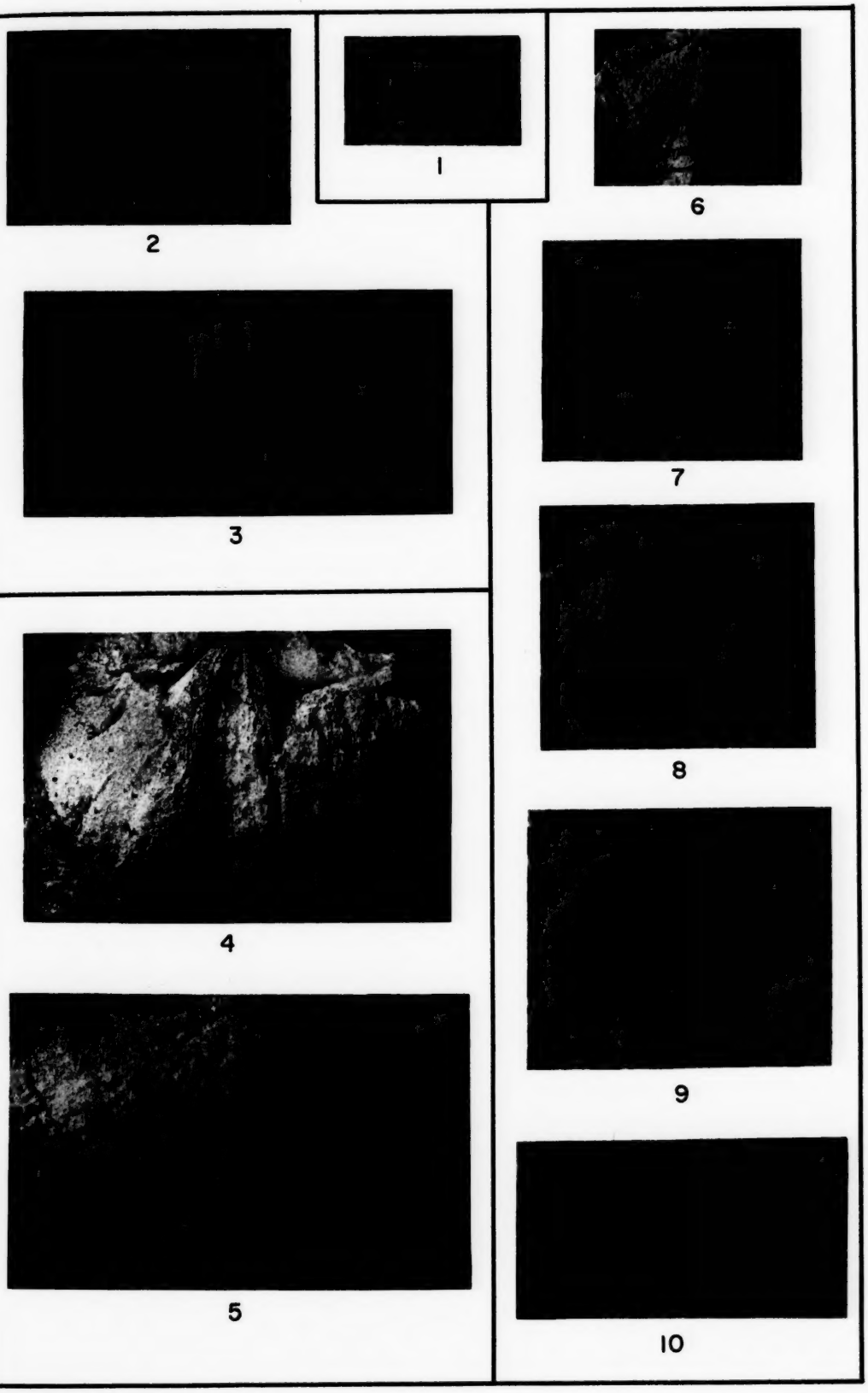
EXPLANATION OF PLATE 92

FIG. *1*—*Hysterolites?* sp. Impression of interior of brachial valve (×1). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126736.

2,3—*Hysterolites* sp. *2*, Impression of interior of brachial valve (×2). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126659; *3*, Impression of interior of pedicle valve (×2). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126658.

4,5—*Acrospirifer macrothyris* (Hall, 1857). *4*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126747A; *5*, Impression of interior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126747B.

6–10—*Hysterolites perimele* (Clarke, 1907). *6*, Impression of interior of brachial valve (×1). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126660; *7*, Impression of interior of pedicle valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126664; *8*, Latex replica of exterior of pedicle valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126662; *9*, Impression of exterior of pedicle valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126662; *10*, Impression of interior of brachial valve (×2) Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126661.



1

2

3

4

5

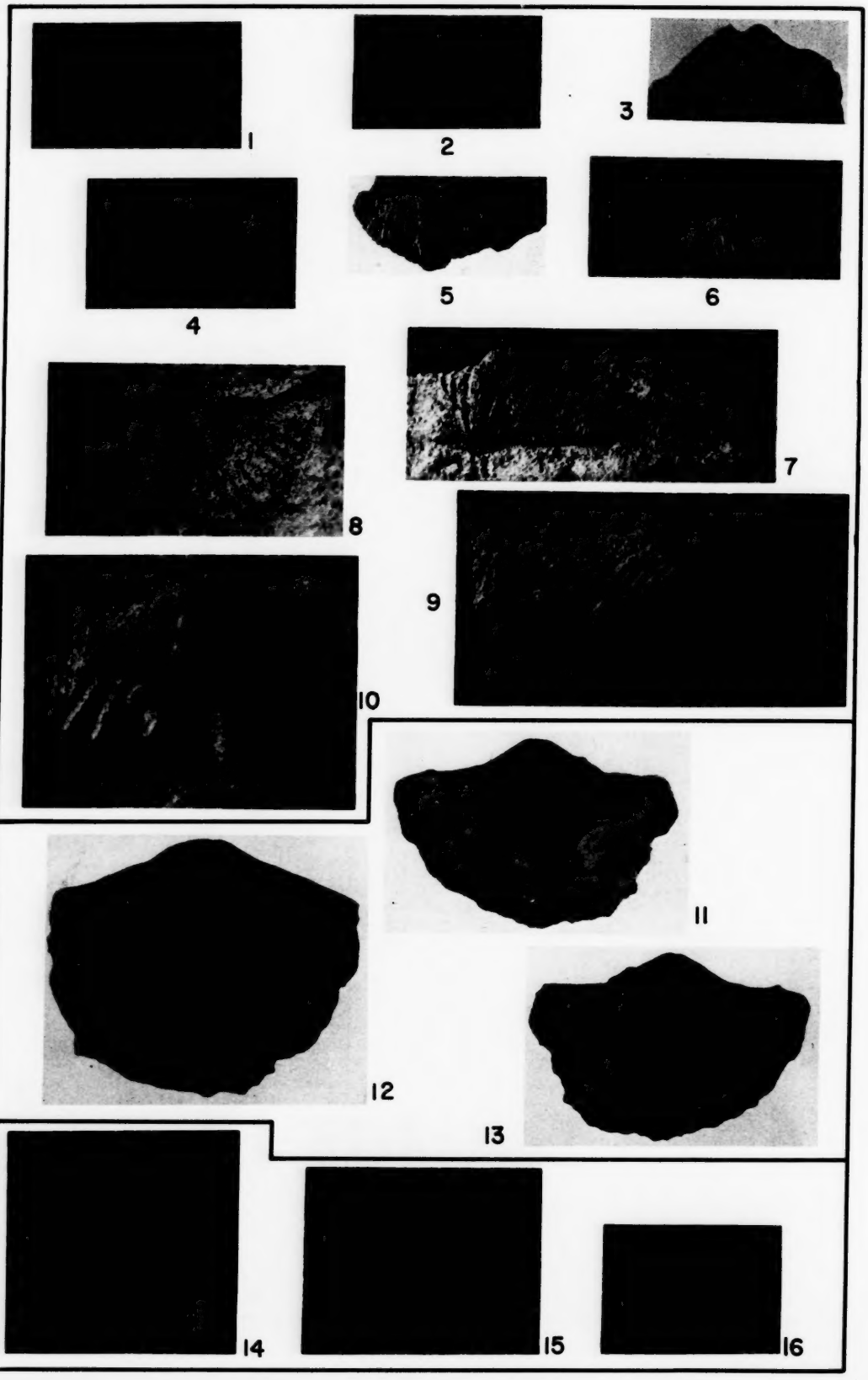
6

7

8

9

10


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

nates slightly anterior of the midlength and rises rapidly in an anterior direction. The greatest width is near the midlength. The pedicle valve bears a very shallow sulcus, corresponding to the fold on the brachial valve. The anterior commissure is uniplicate. The foramen on the pedicle valve is hypothyrid in position. The presence or absence of plates modifying the margins of the delthyrium was not ascertained. The beak of the pedicle valve is slightly incurved. The fine ornamentation consists of concentric growth lamellae.

Brachial interior.—The cardinalia consist of a cardinal plate joined laterally to the inner margins of the laterally directed dental sockets. The median portion of the cardinal plate is occupied by a shallow pit. The cardinal plate is basally supported by a narrow median septum that extends anteriorly to a point short of the midlength. The muscle field is not discernible.

Pedicle interior.—The relatively short, blade-like dental lamellae support stubby hinge teeth. Anteriorly the dental lamellae meet laterally directed ridges of secondary material that postero-laterally bound the deeply impressed muscle field. The umbonal cavities are largely filled with secondary material. The muscle field is deeply impressed into the secondary material which lines the posterior portion of the valve. The muscle field is flabellate, has a subtriangular outline, and extends anteriorly almost half the distance to the anterior margin. The muscle field is about one-third the width of the valve. Weak longitudinal striations are visible on the anterior portion of the muscle field.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Kanouse sandstone.

Distribution.—Strata of Onondaga age in eastern North America.

Figured specimens.—U.S.N.M. 126741, 126741A–B.

EXPLANATION OF PLATE 93

FIGS. *1–10*—*"Spirifer" macra* (Hall, 1857). *1*, Impression of interior of brachial valve (×1). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126732; *2*, Impression of interior of pedicle valve (×1). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126733; *3*, Impression of interior of pedicle valve (posterior view ×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126735; *4*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126735; *5*, Impression of interior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126734; *6*, Impression of exterior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126734. *7*, Impression of interior of brachial valve (posterior view, ×2). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126735B; *8*, Impression of interior of pedicle valve (×2). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126735C; *9*, Impression of interior of brachial valve (×2). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126735B; *10*, Impression of interior of pedicle valve (×2). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126735A.

11–13—*Costispirifer* cf. *C. arenosus* (Conrad, 1839). *11*, Interior of pedicle valve (×1). Connelly conglomerate. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126738; *12*, Exterior of pedicle valve (×1). Connelly conglomerate. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126737; *13*, Exterior of pedicle valve (×1). Connelly conglomerate. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126738.

14–16—*Elytha fimbriata* (Conrad, 1842). *14*, Impression of exterior of brachial valve (×2). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126740A; *15*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126740; *16*, Impression of exterior of brachial valve (×1). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126739.

Genus PENTAGONIA Cozzens, 1846
PENTAGONIA UNISULCATA (Conrad, 1841)
Pl. 94, figs. 9,10

Exterior.—The shell is biconvex, the brachial valve having a greater degree of convexity than the pedicle valve. The shells are subcircular in outline, and the greatest width is near the midlength. The brachial valve bears a rounded fold whose crest is split by a rounded groove which originates in the umbonal region, and the pedicle valve has a sulcus corresponding to the fold on the opposite valve. The anterior commissure is uniplicate. The lateral and anterior margins are rounded. The cardinal margins are terebratulid in form. The exterior is smooth except for concentric growth lamellae which become more pronounced anteriorly.

Pedicle interior.—The short dental lamellae are almost entirely obsolete due to the deposition of secondary material in the umbonal and delthyrial cavities. The dental lamellae support stout hinge teeth, which have a triangular cross-section. The muscle field is deeply impressed into the secondary material lining the posterior of the valve and is restricted to the posterior quarter of the valve. The muscle field consists of two pairs of elongate diductor impressions separated by a low median septum. A spherical pedicle callist occupies the posterior part of the delthyrial cavity. Pallial marks continue from the anterior edge of the muscle field almost to the anterior margin, and consist of an outer pair and an inner pair. The umbonal regions are pustulose, but the

---

EXPLANATION OF PLATE 94

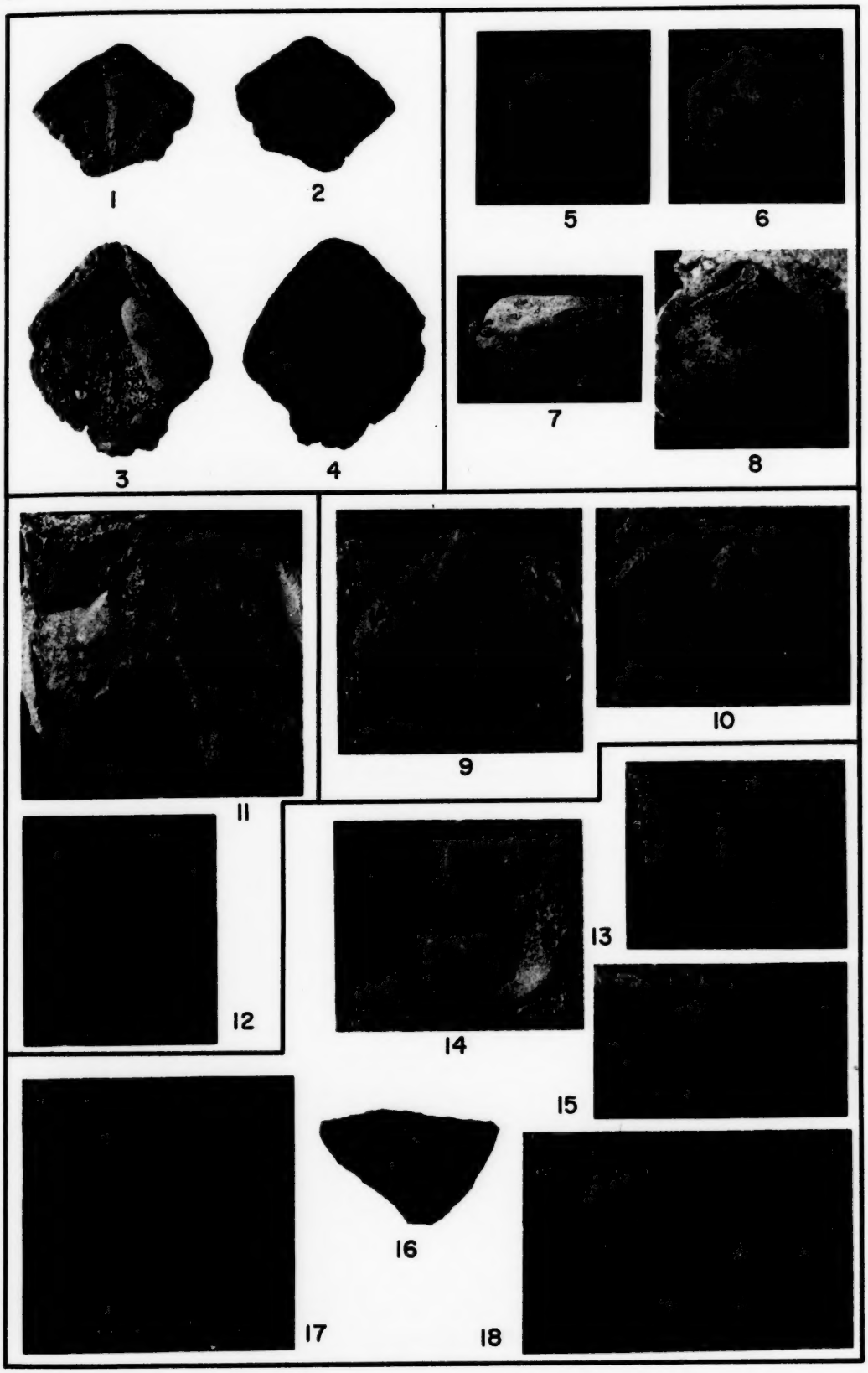
FIGS. *1–4*—*Meristella* sp. *1*, Interior of brachial valve (×1). Connelly conglomerate. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126666; *2*, Exterior of brachial valve (×1). Connelly conglomerate. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126666; *3*, Interior of pedicle valve (×1). Connelly conglomerate. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126667; *4*, Exterior of pedicle valve (×1). Connelly conglomerate. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126667.

5–8,12—*Meristella nasuta* (Conrad, 1840). *5*, Internal impression (brachial view, ×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126741A; *6*, Internal impression (pedicle view, ×1). Kanouse sandstone, Railroad cut at Highland Mills, Orange County, New York, U.S.N.M. No. 126741A; *7*, Internal impression (side view, ×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126741A; *8*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126741B; *12*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126741.

9,10—*Pentagonia unisulcata* (Conrad, 1841). *9*, Impression of interior of pedicle valve (×3). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126743; *10*, Impression of interior of brachial valve (×3). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126742.

11—*Meristella* sp. Impression of interior of pedicle valve (×2). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126665.

13–18—*Cyrtina rostrata* (Hall, 1857). *13*, Impression of exterior of pedicle valve (posterior view, ×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126673; *14*, Impression of interior of pedicle valve (posterior view, ×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126672; *15*, Latex replica of exterior of brachial valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126668; *16*, Impression of interior of pedicle valve (posterior view, ×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126671; *17*, Impression of interior of pedicle valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126670; *18*, Impression of interior of brachial valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126669.

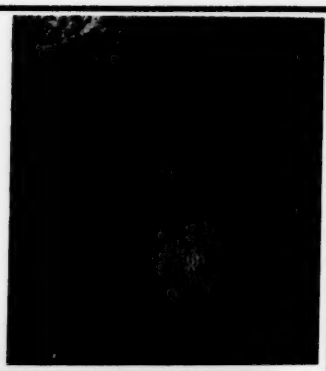

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

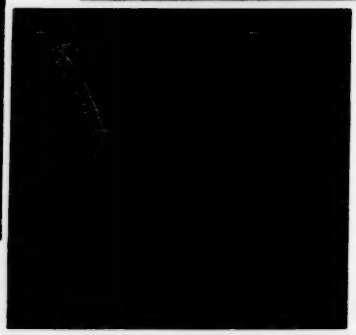
1

2

3

4


5


6

7

8

9

10

11

12

13

14

15

16

peripheral regions of the interior are smooth.

Brachial interior.—The cardinalia consist of a median septum restricted to the posterior third of the valve, which supports a shallow cruralium. The cruralium is laterally bordered by blade-like brachiophores. The muscle field is indistinctly impressed. The interior of the valve is smooth.

Remarks.—The specimens from Highland Mills have a deeper median depression on the brachial valve than do forms from beds of Hamilton age.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Woodbury Creek member of the Esopus formation.

Distribution.—Eastern North America west of the Hudson River.

Figured specimens.—U.S.N.M. 126742–126743.

Unfigured specimens.—U.S.N.M. 125926.

Superfamily PUNCTOSPIRACEA
Family CYRTINIDAE
Subfamily CYRTININAE
Genus CYRTINA Davidson, 1858
CYRTINA ROSTRATA (Hall, 1857)
Pl. 94, figs. 13–18

Exterior.—The pedicle valve is pyramidal in shape with a very elongate interarea. The pedicle valve is often twisted in the apical region possibly indicating that the early growth stage was spent attached to the substrate. The brachial valve is gently convex in form and laterally elongate in outline. The greatest width of both valves is at the hinge line. The pedicle valve bears a broad sulcus which is prolonged anteriorly as a tongue corresponding to the fold of the brachial valve. Both valves are ornamented by lateral costae, uncostate fold and sulcus, and by lamellose concentric growth lines. The

---

EXPLANATION OF PLATE 95

FIGS. *1–4—Stropheodonta demissa* (Conrad, 1842). *1*, Impression of interior of brachial valve (×2). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126678A; *2*, Impression of exterior of pedicle valve (×2). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126678B; *3*, Impression of interior of pedicle valve (×2). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126678C; *4*, Impression of exterior of brachial valve (×2). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126678D.

5–8—Megastrophia hemispherica (Hall, 1857). *5*, Impression of exterior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126679A; *6*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126679; *7*, Impression of interior of pedicle valve (posterior view, ×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126679; *8*, Impression of interior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126679B.

9–12—Leptostrophia sp. *9*, Impression of interior of brachial valve (×3). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126674; *10*, Impression of interior of pedicle valve (×1). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126677; *11*, Impression of exterior of brachial valve (×2). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126675; *12*, Impression of interior of brachial valve (×1). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126676.

13–16—Protoleptostrophia sp. *13*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126676A; *14*, Impression of interior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126676B; *15*, Impression of interior of brachial valve (×2). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126676C; *16*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126676D.

details of the fine ornamentation have not been observed. A moderately wide delthyrium is unfilled by a plate in most of the specimens studied, but the inner face of the delthyrium bears a notch on each side that served to seat the pseudodeltidium. On a single internal impression the imprint of the perforate pseudodeltidium was observed. The pedicle interarea is catacline to steeply apsacline and slightly concave posteriorly. The brachial interarea is gently orthocline and very narrow. Five to six lateral costae were observed on each side of the fold on internal impressions of the brachial valve. The anterior commissure is uniplicate and crenulate.

Brachial interior.—The cardinalia consist of an elevated ctenophoridium from which diverge the blade-like brachiophores. The dental sockets are floored by fulcral plates and bordered anteriorly by the brachiophores. A low median septum occupies the posterior half of the valve. The impression of the external coarse ornamentation is very distinct, although one or two less lateral costae are imprinted on the interior. The adductor muscle impressions have not been observed and probably were impressed very slightly.

Pedicle interior.—A median septum runs from the beak almost to the anterior margin and bisects the spondylium formed by the medially convergent dental lamellae. Posterior of the floor of the spondylium the median septum bisects the tichorhinum. The specimens from Highland Mills are too poorly preserved to indicate the exact nature of the tichorhinum, but the posterior impression of the tube-like structure was observed on one specimen. The stubby hinge teeth are located at the junction of the interarea with the dental lamellae. The impression of the external coarse ornamentation is distinct and as in the brachial valve.

Occurrence.—Railroad and Thruway cuts at Highland Mills, Orange County, New York.

Geologic location.—Highland Mills and Woodbury Creek members of Esopus formation, Central Valley sandstone.

Figured specimens.—U.S.N.M. 126668–126673.

Unfigured specimens.—U.S.N.M. 125910–125911.

Superfamily STROPHOMENACEA
Family STROPHEODONTIDAE
Genus LEPTOSTROPHIA Hall, 1892, emended Williams 1953
LEPTOSTROPHIA sp.
Pl. 95, figs. 9–12

Exterior.—Subequally biconvex shells with a shield-shaped outline. Greatest width is at the straight hinge line. The ornamentation consists of radiating fine costellae which appear to originate both by bifurcation and implantation, but the material from Highland Mills is too poorly preserved to make this point clear.

Pedicle interior.—The two specimens available exhibit large, flabellate diductor fields which are laterally bordered by bounding ridges that originate at the hinge teeth. The hinge line is denticulate. Posteriorly a low median septum divides the muscle impressions.

Brachial interior.—The cardinalia consist of two cardinal process lobes, flanked laterally by socket plates. The hinge line is at least partly denticulate (poor preservation of the lateral extremities prevents certainty as to the presence of denticulations). A low, flat septum divides the posterior portion of the well impressed adductor field, which is bounded laterally by broad ridges of secondary material.

Occurrence.—Thruway cut at Highland Mills, Orange County, New York.

Geologic location.—Central Valley sandstone.

Distribution.—World-wide.

Figured specimens.—U.S.N.M. 126674–126677.

Unfigured specimens.—U.S.N.M. 125914.

Genus PROTOLEPTOSTROPHIA Caster, 1939
PROTOLEPTOSTROPHIA sp.
Pl. 95, figs. 13–16

Exterior.—The pedicle valve is very gently convex, the brachial valve flat. The maximum width is at the straight hinge line. The lateral and anterior margins are evenly rounded. The anterior commissure is rectimarginate. The interarea of the pedicle valve is apsacline, that of the brachial valve

anacline. The pedicle valve interarea is about three times as long as that of the brachial valve. The shells are subrectangular in outline. The ornamentation consists of fine branching costellae crossed by concentric growth lines.

Brachial interior.—The cardinalia consist of stout cardinal process lobes joining anteriorly with a broad notothyrial platform and laterally with lateral ridges. The notothyrial platform narrows anteriorly to a rounded septum which bisects the muscle field. The lateral ridges diverge at an angle of about 90 degrees and laterally bound the deeply impressed muscle field. The muscle field consists of anteriorly expanding adductor impressions which are restricted to the posterior third of the valve. The interior of the valve is smooth except for a pustulose area in the umbonal region and the anterior periphery which is crenulated by the impress of the costellae. The hinge line is wholly denticulate.

Pedicle interior.—The cardinal process pits are well defined and medially separated by a short ventral process. The hinge line is wholly denticulate. The lateral ridges which bound the flabellate muscle field originate laterally from the ventral process pits and diverge at an angle of about 90 degrees. The umbonal cavities are pustulose. The large, flabellate muscle field extends to about the midlength and is about half the width of the valve. The muscle impressions consist of paired, flabellate scars divided medially by a low myophragm which originates at the anterior margin of the ventral process. The muscle field is not divisible in the specimens studied.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Kanouse sandstone.

Distribution.—North America.

Figured specimens.—U.S.N.M. 126676A–D.

Genus STROPHEODONTA Hall, 1852
STROPHEODONTA DEMISSA (Conrad, 1842)
Pl. 95, figs. 1–4

Exterior.—The pedicle valve is evenly convex, the brachial valve gently concave. The straight hinge line is the point of maximum width. The shells are subcircular in outline. The posterior portions of the lateral margins are straight; the anterior margins are evenly rounded. The lateral and anterior commissures are rectimarginate and crenulate. The interarea of the pedicle valve is orthocline; that of the brachial valve is hypercline. The interareas of both valves are short. The coarse ornamentation consists of branching costellae with angular cross-sections separated by narrow interspaces that also have angular cross-sections. A few concentric growth lines are prominent on each valve.

Brachial interior.—The hinge line is semi-denticulate. The cardinalia consist of cardinal process lobes fused basally with a notothyrial platform that narrows anteriorly. The notothyrial platform extends anteriorly for about one-fifth the shell length. Lateral ridges diverge from the lateral faces of each cardinal process lobe. The posterior base of each cardinal process lobe is indented by a shallow pit. The muscle field is restricted to the posterior quarter of the valve and consists of two pairs of elongate adductor impressions separated by narrow septae. The periphery of the valve is strongly crenulated by the impress of the external ornamentation.

Pedicle interior.—Two very shallow pits occur on either side of the ventral process and serve to receive the cardinal process lobes. The hinge line is semi-denticulate. The muscle field extends anteriorly for about one-third the length of the valve and consists of an elongated pair of impressions medially separated by a low myophragm. The periphery is crenulated by the impress of the external ornamentation.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Kanouse sandstone.

Figured specimens.—U.S.N.M. 126678, 126678A–D.

Genus MEGASTROPHIA Caster, 1939
MEGASTROPHIA HEMISPHERICA
(Hall, 1857)
Pl. 95, figs. 5–8

Exterior.—The brachial valve is deeply concave, the pedicle valve strongly convex. The hinge line is straight. The valves are subcircular in outline, with very gently rounded lateral margins and more strongly

rounded anterior margins. The ornamentation consists of parvicostellae crossed by weak, concentric growth lines. The costellae do not radiate directly, but tend to meander slightly in their course to the periphery. The costellae increase by bifurcation. The interarea of the pedicle valve is orthocline to anacline, and relatively short; that of the brachial valve is short and hypercline.

Brachial interior.—The cardinalia consist of cardinal process lobes lateral to which are prominent socket plates. The hinge line is denticulate. The periphery is crenulated by the impress of the external ornamentation.

Pedicle interior.—The hinge line is wholly denticulate. The ventral process pits are deep and laterally bound a prominent median ventral process. The muscle field is small and posteriorly located; it consists of a median, trapezoidal diductor impression which is longitudinally striate.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Kanouse sandstone.

Figured specimens.—U.S.N.M. 126679, 126679A–B.

Unfigured specimens.—U.S.N.M. 125920.

Family LEPTAENIDAE
Genus LEPTAENA Dalman, 1828
LEPTAENA "RHOMBOIDALIS"
(Wilckens, 1769)
Pl. 96, figs. 1,2

Remarks.—A few specimens possessing the concavo-convex profile, strongly geniculate anterior, and concentrically wrinkled form of *Leptaena "rhomboidalis"* were recovered. The material is very fragmentary.

Occurrence.—Highland Mills, Orange County, New York.

Geologic location.—Central Valley sandstone, and Woodbury Creek member of the Esopus formation.

Figured specimens.—U.S.N.M. 126680–126682.

Unfigured specimens.—U.S.N.M. 125928.

Superfamily ORTHOTETACEA
Family SCHUCHERTELLIDAE
Subfamily SCHUCHERTELLINAE
Genus SCHUCHERTELLA Girty, 1904
SCHUCHERTELLA sp. A
Pl. 96, figs. 3,4,6,7,9,11

Remarks.—A single pedicle valve obtained from the Highland Mills member of

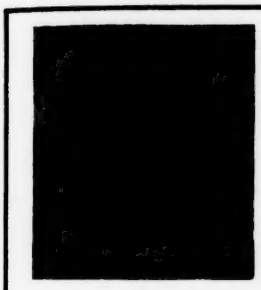
---

EXPLANATION OF PLATE 96

FIGS. *1,2*—*Leptaena "rhomboidalis"* (Wilckens, 1769). *1*, Impression of exterior of pedicle valve (×2). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York, U.S.N.M. No. 126682; *2*, Impression of interior of pedicle valve (×1). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126680.

3–11—*Schuchertella* sp. *3*, Impression of exterior of pedicle valve (×2). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126685; *4*, Impression of exterior of brachial valve (×2). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126687; *5*, Impression of interior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126687A; *6*, Impression of interior of pedicle valve (×2). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126684; *7*, Impression of exterior of pedicle valve (×1). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126683; *8*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126687B; *9*, Impression of interior of pedicle valve (×1). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126683; *10*, Impression of exterior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126687C; *11*, Impression of interior of brachial valve (×2). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126686.

12,13—*Hipparionyx* cf. *H. proximus* Vanuxem, 1842. *12*, Exterior of pedicle valve (×1). Connelly conglomerate. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126688; *13*, Interior of pedicle valve (×1). Connelly conglomerate. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126688.



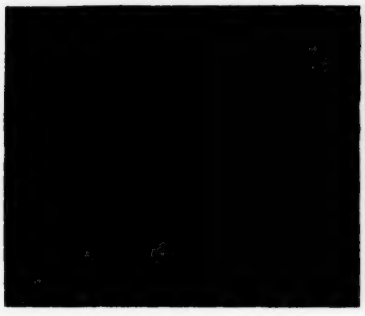
1

2

3

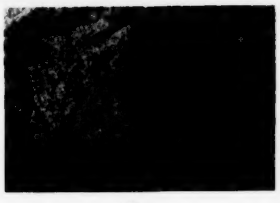
4

5



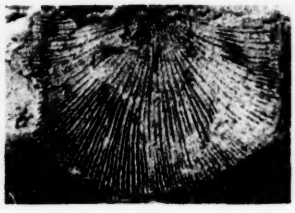
6

7



8

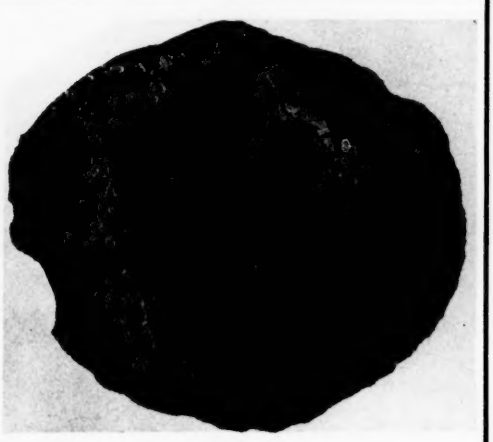
9



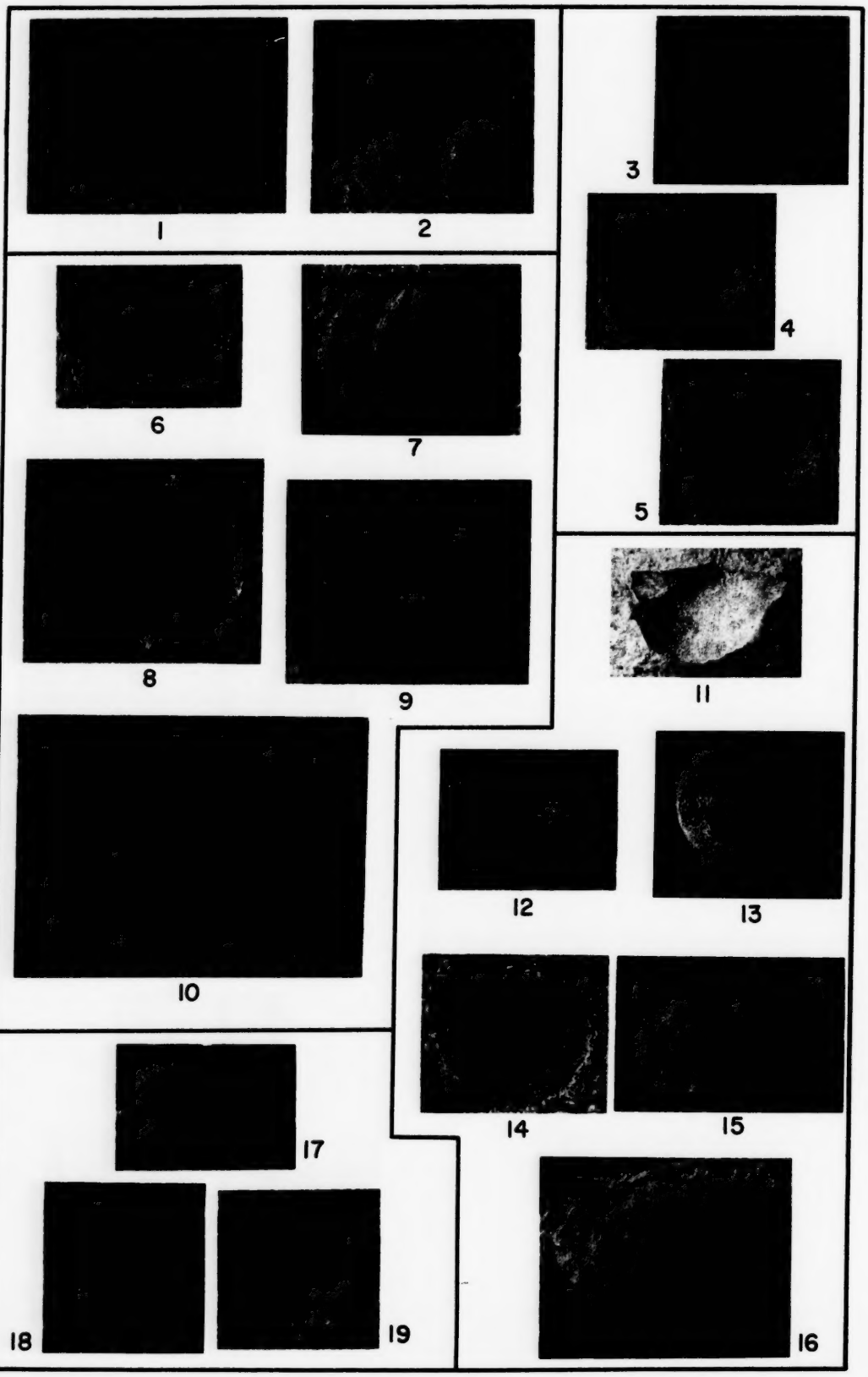
10

11

12



13


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

the Esopus formation and a few specimens from the Woodbury Creek member have the characters of *Schuchertella*, including a moderately convex but not attenuate valve and costellae which increase by intercalation. However, there appear to be short dental plates supporting the hinge teeth, a character not present in *Schuchertella s.s. Schellwienella* possesses dental plates but they occur laterally to the hinge teeth; therefore the Highland Mills specimens do not belong to that genus.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Highland Mills and Woodbury Creek members of the Esopus formation.

Figured specimens.—U.S.N.M. 126683–126687.

"SCHUCHERTELLA" sp. B
Pl. 96, figs. 5,8,10

Exterior.—The brachial valve is gently convex, the pedicle valve gently concave. The straight hinge line is the point of maximum width. The interarea of the brachial valve is anacline, that of the pedicle valve apsacline. Both interareas are of about the

---

EXPLANATION OF PLATE 97

FIGS. *1,2*—*Chonostrophia* sp. *1*, Impression of interior of pedicle valve (×2). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126689; *2*, Impression of exterior of pedicle valve (×2). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126689.

3–5—*Anoplia nucleata* (Hall, 1857). *3*, Impression of interior of pedicle valve (×4). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126690; *4*, Impression of interior of brachial valve (×3). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126691; *5*, Impression of exterior of pedicle valve (×4). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126690.

6–10—*Eodevonaria* cf. *E. gaspensis* Clarke, 1906. *6*, Impression of interior of brachial valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126694; *7*, Impression of interior of pedicle valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126695; *8*, Impression of interior of brachial valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126693; *9*, Impression of exterior of brachial valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126693; *10*, Impression of exterior of pedicle valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126692.

11–16—*Eodevonaria* cf. *E. arcuata* (Hall, 1857). *11*, Impression of exterior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126696A; *12*, Impression of interior of pedicle valve (×1). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126696; *13*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126696B; *14*, Impression of interior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126699; *15*, Impression of exterior of brachial valve (×1). Woodbury Creek member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126697; *16*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126698.

17–19—"*Chonetes*" cf. "*C.*" *nectus* Clarke, 1906. *17*, Impression of exterior of brachial valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126702; *18*, Impression of interior of pedicle valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126701; *19*, Impression of interior of brachial valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126700.

same length. The delthyrium is filled by a large, convex pseudodeltidium. The presence of chilidial structures could not be confirmed due to the poor preservation of the material. The shells have an elliptical outline. The anterior and lateral margins are gently rounded. The anterior and lateral commissures are rectimarginate and crenulate. The coarse ornamentation consists of costellae with angular cross-sections, separated by interspaces with angular cross-sections. The costellae originate by bifurcation.

Brachial interior.—The cardinalia consist of a trifid cardinal process whose posterior face is vertical. Anterior of the cardinal process is a low nototyrial platform that extends anteriorly for about one-sixth the length of the valve. The dental sockets flare laterally and are medially bounded by ridges of secondary material that bound the muscle field. The ridges of secondary material extend antero-laterally for about one-third the length of the valve. The muscle field is flabellate in form, medially divided by a low myophragm, and laterally bounded by the ridges of secondary material. The periphery is crenulated by the impress of the external ornamentation.

Pedicle interior.—Blade-like, laterally directed hinge teeth border the delthyrial cavity and are supported by short dental lamellae. The dental lamellae diverge at an angle of about 60 degrees from the midline. The muscle field is flabellate and poorly impressed. The periphery is crenulated by the impress of the external ornamentation.

Occurrence.—Highland Mills, Orange County, New York.

Geologic location.—Kanouse sandstone.

Figured specimens.—U.S.N.M. 126687A–C.

Genus HIPPARIONYX Vanuxem 1842

HIPPARIONYX sp. cf. H. PROXIMUS Vanuxem, 1842

Pl. 96, figs. 12,13

Remarks.—A single large pedicle valve has the circular outline, costellate ornamentation and muscle impression characteristic of *Hipparionyx*, but the specimen is too poorly preserved to be positively assigned specifically.

Occurrence.—Thruway cut at Highland Mills, Orange County, New York.

Geologic location.—Connelly conglomerate.

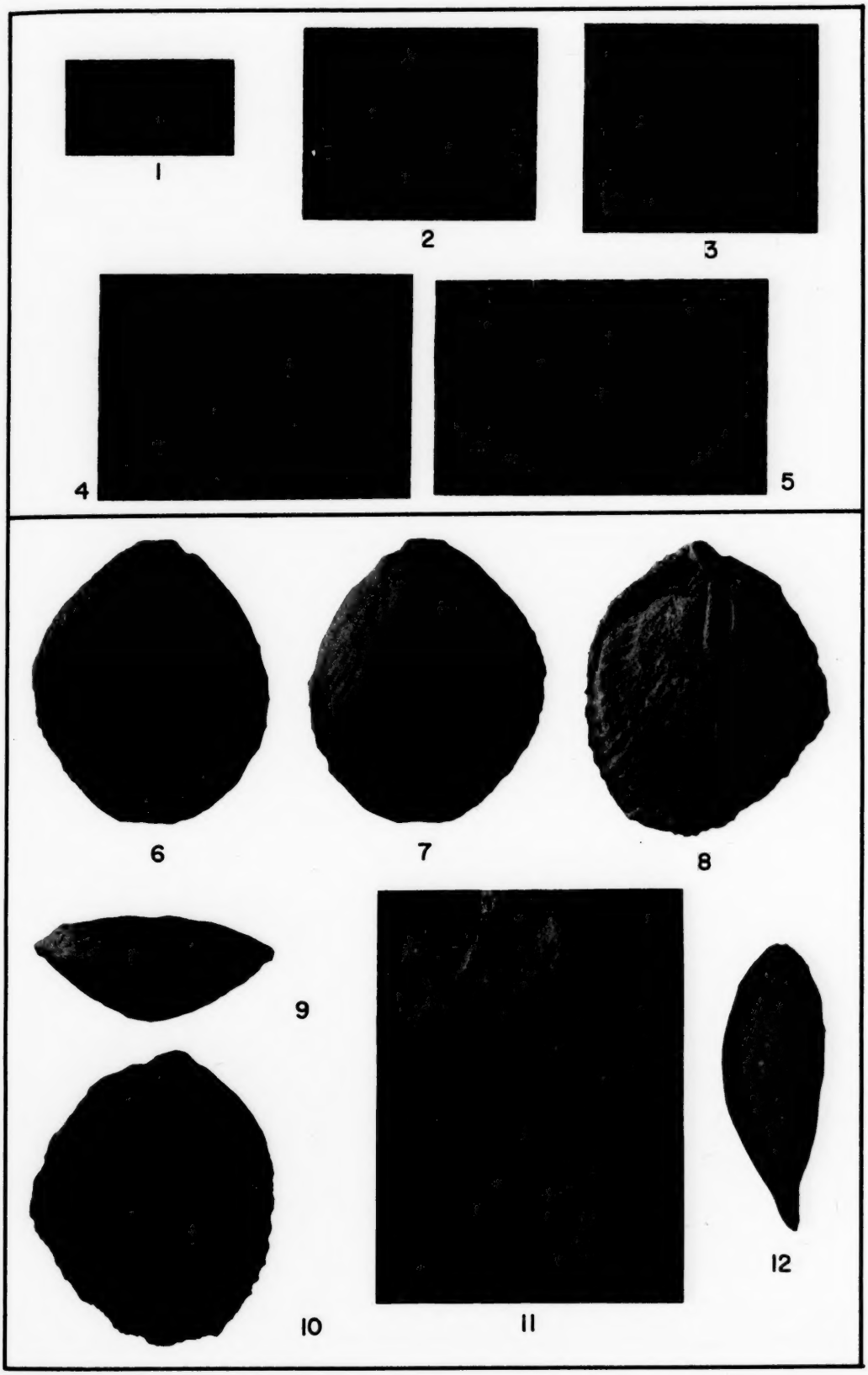
Distribution.—Eastern North America.

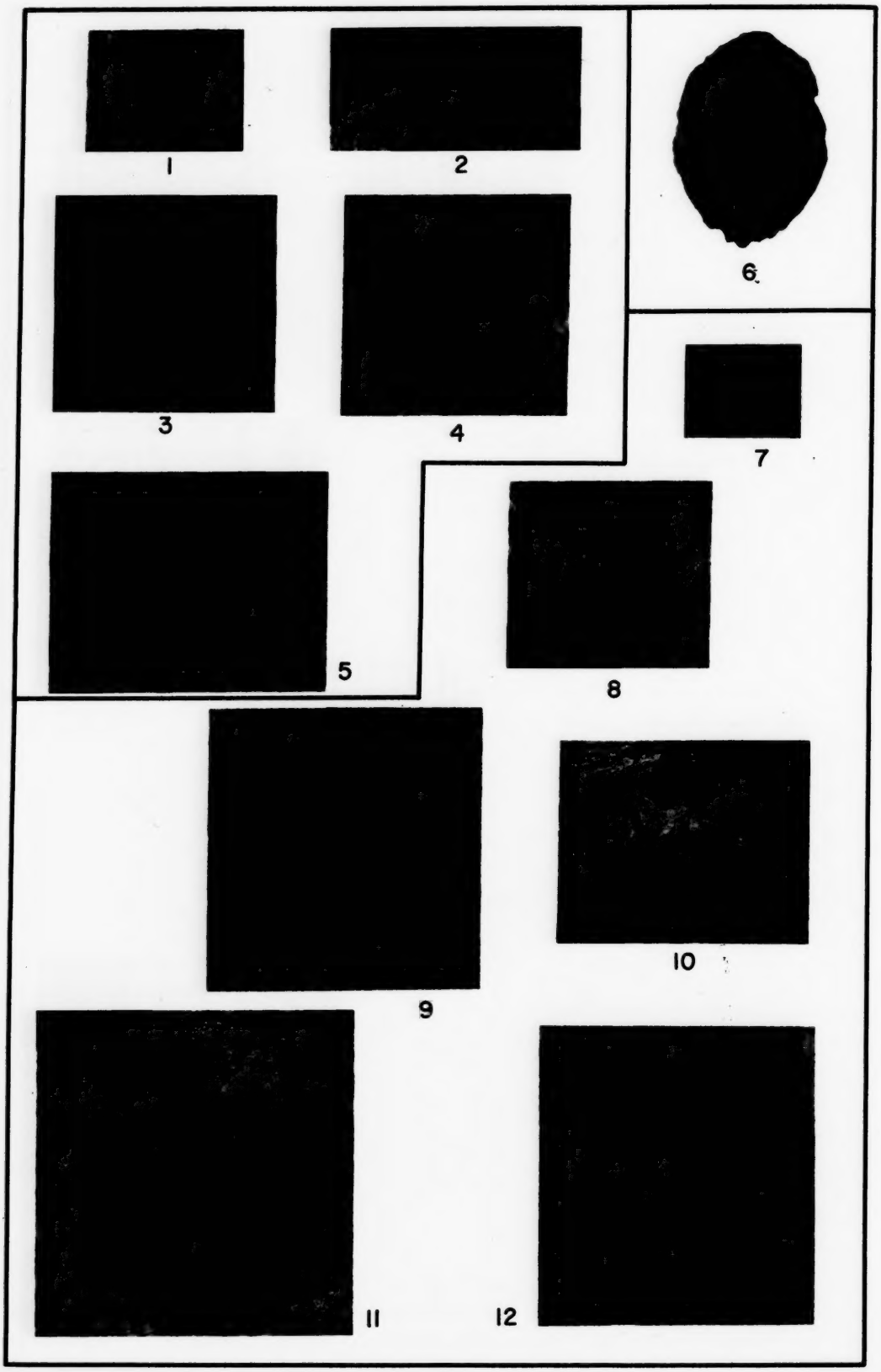
Figured specimens.—U.S.N.M. 126688.

EXPLANATION OF PLATE 98

FIGS. *1–5*—*Chonetes* sp. *1*, Impression of interior of brachial valve (×3). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126705; *2*, Impression of interior of pedicle valve (×3). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126706; *3*, Impression of exterior of pedicle valve (×3). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126706; *4*, Impression of interior of brachial valve (×2½). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126704; *5*, Impression of exterior of pedicle valve (×2). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126703.

6–12—*Nanothyris* cf. *N. subglobosa* (Weller, 1903). *6*, Impression of interior of brachial valve (×3). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126707; *7*, Impression of interior of pedicle valve (×3). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126707; *8*, Impression of interior of brachial valve (×4). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126708; *9*, Impression of interior (posterior view, ×3). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126707; *10*, Impression of interior of pedicle valve (×4). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126708; *11*, Impression of cardinal plate and loop (×4). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126709; *12*, Impression of interior (side view, ×3). Central Valley sandstone. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126707.


1
2
3
4
5
6
7
8
9
10
11
12


1
2
6
3
4
7
5
8
9
10
11
12

Superfamily CHONETACEA
Family CHONETIDAE
Genus EODEVONARIA Breger, 1906
EODEVONARIA sp. cf. E. GASPENSIS
Clarke, 1906
Pl. 97, figs. 6–10

Chonetes (*Eodevonaria*) cf. *arcuata* Clarke *non* Hall, 1909, p. 144, pl. 34, figs. 21–31.

Exterior.—The pedicle valve is moderately convex and the brachial valve gently concave, with the greatest width of both at the hinge line. The outline of the shells is elliptical with the width commonly almost twice the length. The interarea of the pedicle valve is apsacline, whereas that of the brachial valve is hypercline, although the narrowness of the latter makes it difficult to observe on most specimens. Spines bordering the posterior margin of the pedicle valve or fillings of the spine bases were not observed in any of the specimens, but the suite of material available is too small to determine whether spines are invariably absent. The fine ornamentation consists of costellae, which originate mostly by bifurcation and have a somewhat sinuous course as they diverge from the direction of the beak. The costellae are semicircular in cross-section and are separated from each other by narrow interspaces. In some specimens there is a low sulcus on the pedicle valve corresponding to a low fold on the brachial valve. The presence of plates filling the delthyrium and notothyrium could not be confirmed in this collection due to lack of adequate material. The body cavity is very narrow, and the hinge line is straight.

Brachial interior.—The cardinalia consist of a posteriorly directed, bifid cardinal process. The cardinal process lobes join anteriorly, and further forward they are joined by the divergent posterior portions of the septae that laterally border the paired adductor impressions. The adductor impressions are pronounced posteriorly and fade anteriorly; at about the midlength they are no longer distinguishable. The adductor impressions are medially separated by a rounded median septum which extends two-thirds of the distance to the anterior margin and joins the cardinalia posteriorly at about the same place as do the septae that border the muscle field. The interior is covered

---

EXPLANATION OF PLATE 99

FIGS. *1–5*—*Etymothyris* sp. *1*, Impression of interior of brachial valve (×1). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126711. *2*, Latex replica of interior of brachial valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126712. *3*, Impression of interior of brachial valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126714. *4*, Impression of exterior of pedicle valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126713. *5*, Impression of interior of pedicle valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126713.

6—*Rensselaeria* cf. *R. elongata* (Conrad, 1839). Exterior of pedicle valve (×1). Connelly conglomerate. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126710.

7–12—*Prionothyris diobolaris* (Clarke, 1909). *7*, Impression of interior of brachial valve (×1). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126721; *8*, Impression of interior of brachial valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126722; *9*, Impression of exterior of pedicle valve (×2). Highland Mills member of Esopus formation. Highland Mills, Orange County, New York. U.S.N.M. No. 126720; *10*, Impression of interior of brachial valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126721; *11*, Impression of interior of brachial valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126719; *12*, Impression of interior of pedicle valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126720.

with low knobs which are the surface expression of the pseudopunctae. The impression of the external ornamentation is strong around the margins of the shell but becomes less pronounced toward the postero-median direction. The posterior margin is denticulate. The small, weakly indented dental sockets are bordered medially by the cardinal process lobes. Two lateral ridges gradually diverge anteriorly from the postero-median region near the hinge line.

Pedicle interior.—The hinge teeth are low and rounded, articulation being largely accomplished by means of the wholly denticulate hinge line. A low median septum runs from the posterior portion of the shell to about half the distance to the anterior. The surface of the interior is pseudopunctate and is crenulated by the impress of the external ornamentation. Two postero-lateral ridges diverge laterally from the postero-median portion of the shell and then curve anteriorly. They correspond to the similar ridges in the brachial valve and probably aided in articulation.

Comparison.—The material from Highland Mills most closely resembles *E. gaspensis* Clarke, 1906, from the Gaspe sandstone in having a moderately convex pedicle valve, as contrasted with the highly convex pedicle valve of *E. arcuata* (Hall, 1857). In the absence of sufficient comparative material and an inadequate sample from Highland Mills, the material cannot be positively identified.

Occurrence.—Highland Mills, Orange County, New York.

Geologic location.—Highland Mills member of the Esopus formation.

Distribution.—Northeastern North America.

Figured specimens.—U.S.N.M. 126692–126695.

Unfigured specimens.—U.S.N.M. 125913.

EODEVONARIA sp. cf. E. ARCUATA (Hall, 1857)
Pl. 97, figs. 11–16

Remarks.—A few large, highly convex chonetids possessing denticulate hinge lines and the general form of *E. arcuata* were collected from the Woodbury Creek member of the Esopus formation and the Kanouse sandstone. These specimens have a more convex form and attain a larger size than do the specimens of *E.* cf. *E. gaspensis* found in the Highland Mills member.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Woodbury Creek member of the Esopus formation and the Kanouse sandstone.

Distribution.—North America.

Figured specimens.—U.S.N.M. 126696–126699, 126696A,B.

Unfigured specimens.—U.S.N.M. 125922.

Genus CHONETES Fischer, 1837
"CHONETES" sp. cf. "C." NECTUS Clarke, 1906
Pl. 97, figs. 17–19

Chonetes highlandensis Clark, 1909, p. 144–145, pl. 34, figs. 32–41.

Exterior.—The pedicle valve of small specimens (up to about 2 millimeters wide) is almost hemispherical, although the hinge line is straight. Specimens more than about 2 millimeters wide show an abrupt change in convexity, with the anterior portions appearing as a far less convex "rim" about the highly convex earlier portion of the shell. The brachial valve is evenly concave and does not display the abrupt change in curvature shown by the opposing valve. The inclination of the interareas of neither valve could be determined on the limited material at hand. Both valves are ornamented with relatively coarse costellae which bifurcate anteriorly at the point where the abrupt change in curvature takes place. The anterior commissure is crenulate. Spines along the posterior margin of the pedicle valve were not observed in the available material.

Brachial interior.—The cardinalia consist of a prostrate, posteriorly directed, terminally bifid cardinal process. Lateral to the sides of the cardinal process are the shallow dental sockets which also abut the hinge line posteriorly. Posterior ridges parallel the median position of the interarea and slowly curve toward the anterior as the ears are approached. Paired ridges, apparently formed from coalescent pseudopunctae aligned in rows, diverge from the base of the cardinalia and laterally enclose the feebly impressed adductor field. These paired ridges reach almost to the anterior margin. The in-

terior is highly pustulose owing to the presence of pseudopunctae. The impression of the external costellae is prominent around the fringe of the valve, but is not impressed postero-medially.

Pedicle interior.—Stout, stubby hinge teeth border the delthyrial cavity and are not supported by dental lamellae. A bladelike median septum reaches from the rear of the delthyrial cavity two-thirds of the distance to the anterior margin. The impression of the external ornamentation is prominent near the anterior and lateral margins. The muscle field is not easily discernible.

Comparison.—"*C.*" sp. cf. "*C.*" *nectus* is similar in all characters to "*Chonetes*" *nectus* from the upper part of the Moose River sandstone in Maine, but lack of adequate material from Highland Mills precludes a positive identification. No other chonetid known to me possesses the peculiar ornamentation of this form.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Highland Mills member of the Esopus formation.

Distribution.—Northeastern North America.

Figured specimens.—U.S.N.M. 126700–126702.

Unfigured specimens.—U.S.N.M. 125912.

"CHONETES" sp.
Pl. 98, figs. 1–5

Exterior.—The pedicle valve is gently convex and has an elliptical outline, the width being about one and one-half times the length. The greatest width of the shell is at the hingeline, which is straight. The brachial valve is gently concave. The pedicle interarea is steeply apsacline, the brachial interarea steeply hypercline to anacline. The fine ornamentation consists of very narrow, threadlike, somewhat sinuous costellae which originate mainly by bifurcation. The costellae are rounded in cross-section and have relatively narrow interspaces. The interspaces are regularly interrupted by the pustulose protrusions of the pseudopunctae; such protuberances are absent on the costellae. The anterior commissure is rectimarginate. The lateral margins of the shell are almost at right angles to the interarea, giving the shell a sub-rectangular appearance posteriorly. As the anterior part of the shell is approached the lateral margins round medially. About 4 to 6 spines occur along the posterior margin of the pedicle valve.

Brachial interior.—The cardinalia consist of a posteriorly directed, terminally bifid cardinal process which merges anteriorly with the posterior ridges, the latter being subparallel to the interarea. The adductor impressions are only noticeable posteriorly, just anterior to the cardinalia. The dental sockets are relatively deep and are excavated in the medial portion of the interarea. The impression of the external costellae is strongly marked until the cardinalia are reached.

Pedicle interior.—Stout hinge teeth occur along the margin of the delthyrial cavity. A short median septum occurs in the delthyrial cavity and extends anteriorly for a short distance. The muscle field is not visibly impressed. The filling of the spine bases is noticeable on a few specimens. The impress of the external ornamentation is similar to that of the brachial valve.

Comparison.—The material is too poorly preserved to be assigned specifically but is similar to *Chonetes hudsonicus* Clarke, 1900.

Occurrence.—Thruway cut at Highland Mills, Orange County, New York.

Geologic location.—Central Valley sandstone.

Figured specimens—U.S.N.M. 126703–126706.

Unfigured specimens.—U.S.N.M. 125917.

Genus CHONOSTROPHIA Hall and Clarke, 1892

CHONOSTROPHIA sp.
Pl. 97, figs. 1,2

Remarks.—A single pedicle valve, obtained from the Woodbury Creek member of the Esopus formation, has the geniculate form of *Chonostrophia*. Unfortunately, the ornamentation is too poorly preserved to enable one to determine whether it consists of uniformly fine costellae as in "*C.*" *complanata* or of both coarse and fine costellae as in *C. reversa*.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Woodbury Creek member of the Esopus formation.

Figured specimen.—U.S.N.M. 126689.

Genus ANOPLIA Hall and Clarke, 1892
ANOPLIA NUCLEATA (Hall, 1857)
Pl. 97, figs. 3–5

Remarks.—Smooth, spineless chonetids are abundant in the Woodbury Creek member and conform in all respects to *A. nucleata*.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Woodbury Creek member of the Esopus formation.

Figured specimens.—U.S.N.M. 126690–126691.

Unfigured specimens.—U.S.N.M. 125923.

Suborder TEREBRATULOIDEA
Superfamily TEREBRATULACEA
Family CENTRONELLIDAE
Subfamily RENSSELAERIINAE
Genus NANOTHYRIS Cloud, 1942
NANOTHYRIS sp. cf. N. SUBGLOBOSA (Weller, 1903)
Pl. 98, figs 6–12

Exterior.—The shells are unequally biconvex, the brachial valve being very gently convex and the pedicle valve being about twice as deep and somewhat naviculate in form. The shells are longitudinally elongated with the greatest width near the midlength. The lateral margins are evenly rounded. The anterior commissure is rectimarginate and weakly crenulate. The outline of the shell is subpentagonal due to the relatively straight cardinal margins, which diverge anterolaterally, and the very gently rounded anterior margin. The cardinal margins are terebratulid in form. The beak of the pedicle valve is suberect. The presence or absence of deltidial plates could not be determined from this material. The ornamentation consists of relatively small, low, rounded costellae which are located around the periphery of the shell. The radial ornamentation is crossed by concentric growth lines. The umbonal regions are smooth.

Pedicle interior.—Short dental lamellae bound either side of the delthyrial cavity. The dental lamellae are concave medially and their lower part curves in an anteromedial direction. The muscle field is very poorly impressed and appears to be restricted to the delthyrial cavity and not to extend anterior of the dental lamellae.

EXPLANATION OF PLATE 100

FIGS. *1,2*—*"Prionothyris"* sp. *1*, Impression of interior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126716A; *2*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126716B.

3,4—*Beachia* sp. *3*, Interior of brachial valve (×2). Connelly conglomerate. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126715; *4*, Exterior of brachial valve (×2). Connelly conglomerate. Thruway cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126715.

5–7—*Amphigenia preparva* Boucot, n. sp. *5*, Impression of interior of pedicle valve (×2). Woodbury Creek member of Esopus formation. Thruway at Highland Mills, Orange County, New York. Holotype U.S.N.M. No. 126718F; *6*, Impression of interior of pedicle valve (×1). Woodbury Creek member of Esopus formation. Thruway at Highland Mills, Orange County, New York. Holotype U.S.N.M. No. 126718F; *7*, Impression of interior of pedicle valve (×1). Woodbury Creek member of Esopus formation. Thruway at Highland Mills, Orange County, New York. U.S.N.M. No. 126718G.

8–13—*Amphigenia elongata* (Vanuxem, 1842). *8*, Impression of exterior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126718A; *9*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126718A; *10*, Internal view of silicified pedicle valve (×2). Lower part of Onondaga limestone. 2½–3 miles ENE. of Leroy, New York. U.S.N.M. No. 94502; *11*, Impression of interior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126718B; *12*, Impression of interior of brachial valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126718C; *13*, Impression of interior of pedicle valve (×1). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126717D.

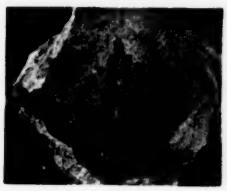
1

2

3

4

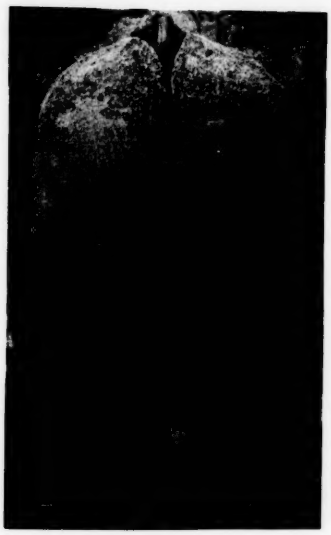
5



6

7

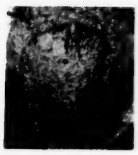
8



9

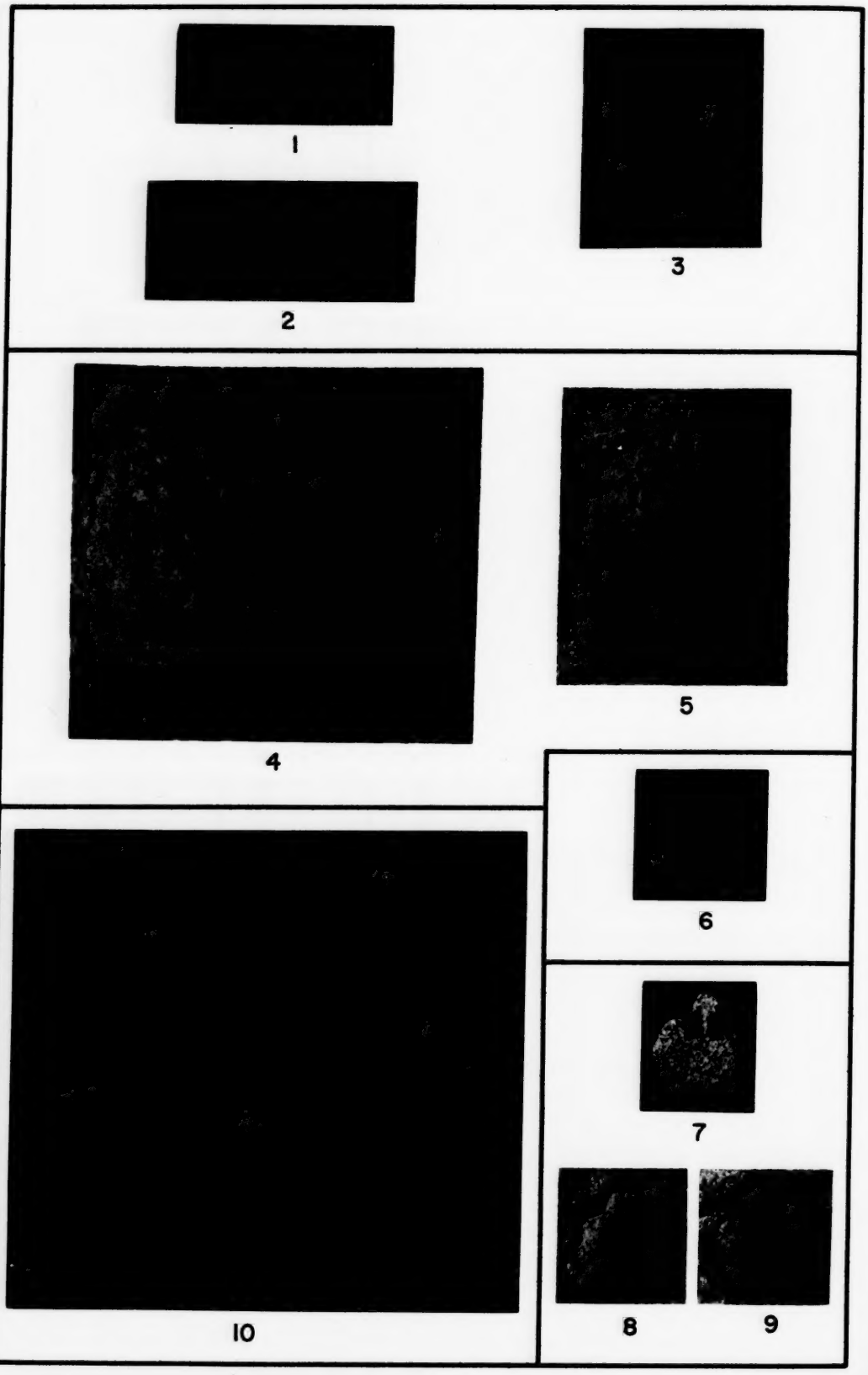
10

12



11

13


1
2
3
4
5
6
7
8
9
10

Brachial interior.—The cardinalia consist of a cardinal plate which is apically perforate and supported by crural plates. The crural plates are relatively long and extend anteriorly about one-quarter of the length of the valve. The cardinal plate appears to be tripartite, being formed from a pair of hinge plates joined medially by a third plate which extends from the posteriorly located apical foramen to the anterior margin of the cardinal plate. This third plate expands anteriorly. The cardinal plate is concave upwards. The crus originates from the anterior part of the hinge plates and extends upward to terminate in the pointed tips of the crural points and in a medial direction to form the lateral band. The transverse plate is very short and located slightly anterior of the midlength. The transverse plate is bisected by a spine which appears to project both anteriorly and posteriorly on the one impression studied. The anterior position of the loop most closely resembles that figured by Cloud (1942,. p 44, fig. 7, pt. 6) for *Centronella*, whereas the posterior part most closely resembles that figured by Cloud (*op cit.* 1942, fig. 7–1, pt. 1) for *Nanothyris*.

Comparison.—The material from Highland Mills most closely resembles *Nanothyris subglobosa*, but the well documented comparative material available for study is inadequate for a positive determination of the specific identity of our specimens. Crushing of the specimens from Highland Mills has probably reduced the convexity of the specimens by at least one-quarter to one-third.

Occurrence—Thruway cut at Highland Mills, Orange County, New York.

Geologic location.—Central Valley sandstone.

Distribution.—Eastern and central North America.

Figured specimens.—U.S.N.M. 126707–126709.

Unfigured specimens.—U.S.N.M. 125916.

Genus RENSSELAERIA Hall. 1859

RENSSELAERIA sp. cf. R. ELONGATA (Conrad, 1839)

Pl. 99, fig. 6

Discussion.—A single poorly preserved pedicle valve possessing the form and costellate ornamentation of *Rensselaeria* was found in the Connelly conglomerate. The interior of the specimen is filled with

---

EXPLANATION OF PLATE 101

FIGS. *1–3—Amphigenia chickasawensis* Boucot, n. sp. *1*, Impression of interior (side view, ×1). Strata of Onondaga age. 4280′–4295′, Union Producing Co., Dinsmore No. 1 Well, Sec. 28, T. 12 S, R 3 E, Chickasaw Co., Miss. Holotype U.S.N.M. No. 123380; *2*, Impression of interior of pedicle valve (posterior view, ×2). Strata of Onondaga age. 4280′–4295′, Union Producing Co., Dinsmore No. 1 Well, Sec. 28, T. 12 S, R 3 E, Chickasaw Co.,Miss. U.S.N.M. No. 126212C; *3*, Impression of interior (brachial view, ×1). Strata of Onondaga age. 4280′–4295′, Union Producing Co., Dinsmore No. 1 Well, Sec. 28, T. 12S, R 3 E, Chickasaw Co., Miss. Holotype U.S.N.M. No. 123380.

4,5—Amphigenia sp. *4*, Impression of interior of pedicle valve (×2). Maecuru beds. Rio Curva, Para, Brazil. U.S.N.M. No. 24315; *5*, Impression of interior of brachial valve (×2). Maecuru beds. Rio Curva, Para, Brazil. U.S.N.M. No. 24315.

6—Amphigenia curta (Meek and Worthen, 1868). Impression of interior (posterior view, ×1). Clear Creek chert (upper). Alto Pass Road, 1.2 miles north of intersection with Illinois, 146, NW¼, NE¼, 15–12S–2W, NW of Jonesboro, Illinois. U.S.N.M. No. 123382A.

10—Amphigenia elongata (Vanuxem, 1842). Interior of pedicle valve (×2). Showing medially conjunct dental lamellae forming septum. Onondaga limestone. Western New York. U.S.N.M. No. 126264.

7–9—Centronella sp. *7*, Impression of interior (brachial view, ×3). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126264A; *8*, Impression of interior of pedicle valve (×3). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126264B; *9*, Impression of interior of pedicle valve (×3). Kanouse sandstone. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126264C.

very resistant quartzite and has not been excavated, but the exterior is very similar to that of *R. elongata*.

Occurrence.—Thruway cut at Highland Mills, Orange County, New York.

Geologic location.—Connelly conglomerate.

Distribution.—The genus *Rensselaeria* is known only from eastern North America.

Figured specimens.—U.S.N.M. 126710.

Genus ETYMOTHYRIS Cloud, 1942
ETYMOTHYRIS sp.
Pl. 99, figs. 1–5

Exterior.—Unequally biconvex shells, the the brachial valve being gently rounded and the pedicle valve being much deeper and naviculate in form. The outline of the available specimens is subcircular, with the greatest width near the midlength. The lack of an elongate outline may be due to breakage, although most of the specimens examined do not show any obvious evidence of breakage along the anterior margins of the valve. The anterior and lateral margins are evenly rounded. The anterior commissure is rectimarginate. The cardinal margins are very restricted and subterebratulid in form. The beak of the pedicle valve is short and slightly incurved. The delthyrium does not appear to have been modified. There is no evidence of costellae on the specimens studied, but this absence might be due to a combination of abrasion and an originally smooth umbo from which the radially costellate anterior portion has been broken during sorting.

Pedicle interior.—The dental lamellae are long and extend almost to the anterior margin. They are subparallel anteriorly, but in the delthyrial region of the valve they diverge laterally from the plane of the vertical and are posteriorly attached to the rear of the shell just below the commissure. The muscle field, which consists of a pair of elongate diductors medially separated by a low myophragm, is very deeply impressed in the secondary material which floors the valve. The hinge teeth are small, pointed, and laterally directed. The interior of the valve is smooth and uncrenulated. The rear of the delthyrial cavity is occupied by a rounded chamber which may have served as the site of the pedicle callist.

Brachial interior.—The cardinalia consist of a cardinal plate formed from medially conjunct hinge plates and supported by a pair of crural plates. The posterior portion of the cardinal plate contains a foramen. The long crural plates extend anteriorly to bound the posterior portion of the muscle field laterally. The stubby brachiophores are directed antero-laterally and form the antero-medial face of the dental sockets. The muscle field is weakly impressed and consists of paired, elongate adductor impressions. The deposition of secondary material tends to obscure the foramen in the cardinal plate and to make the junction of the crural plates and cardinal plate obscure.

Comparison.—The material from Highland Mills is inadequate as the basis for specific identification. The outline of the shells from Highland Mills is not as elongate as in *E. gaspensis*, but this difference in outline might be ascribed to the breakage of the shells from Highland Mills. The unornamented umbonal regions of the material from Highland Mills are unlike those of the specimens from Gaspe.

Occurrence.—Railroad and Thruway cuts, Highland Mills, Orange County, New York.

Geologic location.—Highland Mills member and lower half of Woodbury Creek member of the Esopus formation.

Figured specimens.—U.S.N.M. 126711–126714.

Unfigured specimens.—U.S.N.M. 125899.

Subfamily EURYTHYRINAE
Genus PRIONOTHYRIS Cloud, 1942
PRIONOTHYRIS DIOBOLARIS (Clarke, 1909)
Pl. 99, figs, 7–12

Exterior.—The shells are subequally convex, with the brachial valve less convex than the pedicle valve. The outline of the shells is subcircular to longitudinally elongate and ellipsoidal. The cardinal margins are submegathyrid in form. The lateral margins of the valves are slightly introverted. The anterior margin is rectimarginate and rounded. The lateral margins are gently rounded. The greatest width is slightly posterior of the midlength, and the planareas are about three-quarters as wide as the maximum width. No radial ornamentation has been observed, but concentric growth lines are well

defined. The beak of the pedicle valve is nearly straight, and the pedicle foramen is submesothyrid to mesothyrid. The deltidial plates are small and conjunct.

Pedicle interior.—The interior of the pedicle valve is characterized by short dental lamellae which become almost entirely obsolete due to the deposition of secondary material in the umbonal cavities. The hinge teeth are flat, plate-like, and parallel to the dental lamellae. The elongate muscle field is deeply impressed and extends to about the midlength. It consists of paired diductor impressions (medially separated by a low, rounded myophragm) which posteriorly surrounds a pair of small elliptical adductor impressions. The upper portion of the delthyrial cavity is indented by antero-laterally diverging grooves which serve to seat the postero-medial portion of the brachial valve. A bulbous chamber occupied by the pedicle callist is located immediately below the foramen.

Brachial interior.—The cardinalia consist of a cardinal plate formed from conjunct hinge plates supported by crural plates. The cardinal plate supports the cardinal process, which in small specimens is a terminally bifid, pillar-like structure whose lobes are posteriorly grooved and in larger specimens is a large mound-like structure, medially grooved, and posteriorly indented by two parallel grooves whose lateral posteriors are deeply striated by basally diverging slits. The dental sockets are bounded anteriorly by the cardinal plate and posteriorly by the hinge line. The sockets are laterally directed. The muscle field is well impressed posteriorly and consists of paired, elongate adductor impressions separated by a thin myophragm. The muscle field extends anteriorly to a point about two-thirds of the distance to the anterior margin.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Highland Mills member of Esopus formation.

Figured specimens.—U.S.N.M. 126719–126722.

Unfigured specimens.—U.S.N.M. 125898.

"PRIONOTHYRIS" sp.
Pl. 100, figs. 1,2

Exterior.—The shells are subequally biconvex, with the brachial valve less convex than the pedicle valve. The outlines of the few specimens available are longitudinally elongate. The cardinal margins are submegathyrid in form. The lateral margins of both valves are slightly introverted. The anterior and lateral margins are evenly rounded. The anterior commissure is rectimarginate. The maximum width is near the midlength. The planareas are about two-thirds as wide as the maximum width. The beak of the pedicle valve is suberect, and the pedicle foramen is mesothyrid.

Brachial interior.—The cardinalia consist of a cardinal plate, formed from conjunct hinge plates supported by crural plates, and a cardinal process. The cardinal plate supports the terminally bifid, pillar-like cardinal process. The posterior face of the cardinal process is smooth. The dental sockets flare laterally. The crura originate at the frontal margins of the cardinal plate and are directed anteriorly. The muscle field is well impressed posteriorly and consists of paired, elongate adductor impressions separated by a thin myophragm. The muscle field is about one-third the maximum width of the valve.

Pedicle interior.—The interior of the pedicle valve is characterized by short dental lamellae which become almost entirely obsolete due to the deposition of secondary material in the umbonal cavities. The hinge teeth are stubby. The elongate muscle field, deeply impressed and extending to about the midlength, consists of paired diductor impressions medially separated by a low, rounded myophragm. Posteriorly the diductor impressions surround a pair of small elliptical adductor impressions. The upper portion of the delthyrial cavity is indented by antero-laterally diverging grooves which serve to seat the postero-medial portion of the brachial valve.

Discussion.—The posteriorly unstriated or grooved cardinal process of this form is unlike that of species belonging to *Prionothyris* s.s. This form, is, however, similar to undescribed specimens studied by the writer from the upper, Onondaga-age portion of the Moose River sandstone.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geological location.—Kanouse sandstone.

Figured specimens.—U.S.N.M. 126716A, B.

Genus BEACHIA Hall and Clarke, 1893
BEACHIA sp.
Pl. 100, figs. 3,4

Discussion.—A single fragmentary brachial valve has the generic form of *Beachia*, including a cardinal plate formed from conjunct hinge plates and basally supported by crural plates. The exterior of the valve is smooth.

Occurrence.—Thruway cut at Highland Mills, Orange County, New York.

Geologic location.—Connelly conglomerate.

Figured specimen.—U.S.N.M. 126715.

Subfamily AMPHIGENINAE Cloud, 1942
Genus AMPHIGENIA Hall, 1867

Diagnosis.—The genus *Amphigenia* is characterized by the presence in the pedicle valve of a spondylium, usually supported by a median septum and buttressed posteriorly by a pair of small plates. It is recommended that the pair of plates buttressing the spondylium be termed mystrochial plates. The median septum is the fused continuation of the dental lamellae forming the spondylium, and is not distinct from them.

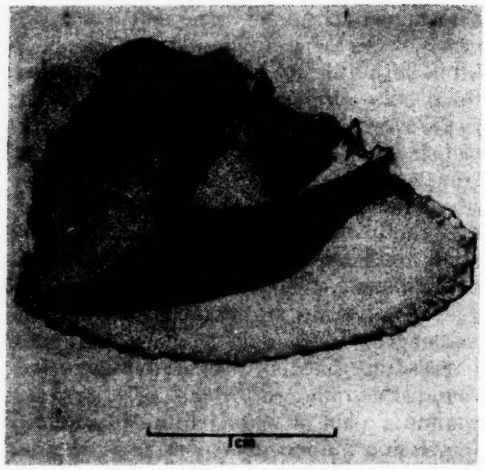
Comparison.—No other described terebratuloid genus posseses a spondylium in its pedicle valve.

Geologic range.—Late Lower Devonian (strata of Woodbury Creek to Onondaga age).

Distribution.—Eastern North America and Brazil (Pl. 101, figs. 4,5).

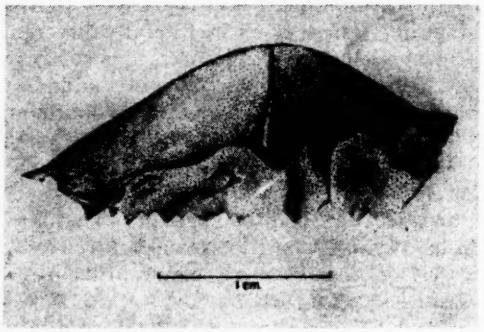
AMPHIGENIA ELONGATA (Vanuxem, 1842)
Pl. 100, figs. 8–13; pl. 101, fig. 10

Exterior.—The shell is unequally biconvex, the naviculate pedicle valve being about twice as deep as the gently convex brachial valve. The outline of the shell is subcircular to longitudinally elongate and ellipitical. The maximum width is located from one-third to one-half of the distance anterior from the beak. The anterior commissure is rectimarginate. The lateral margins are straight to rounded, and the anterior margin is rounded. The hinge line is straight. The ornamentation consists of concentric growth lines. The cardinal margins are subterebratulid in form. The beak of the pedicle valve is incurved.

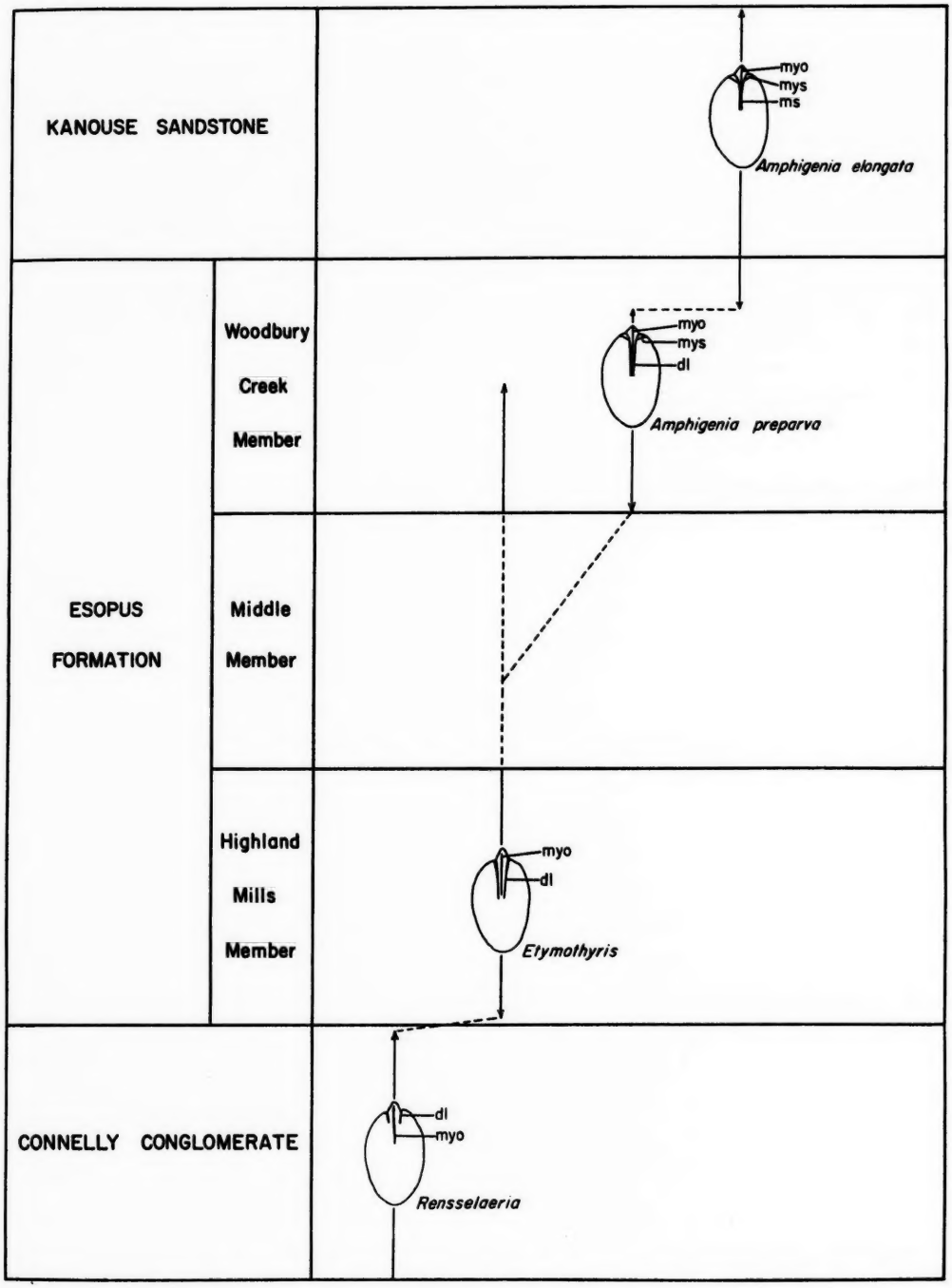


TEXT-FIG. 3—*Amphigenia elongata* (Vanuxem, 1842). Internal view showing mystrochial plates supporting the posterior portions of the spondylium. Lower part of Onondaga limestone. 2½ to 3 miles E. N. E. of Leroy, New York. U.S.N.M. No. 94502.

Brachial interior.—The cardinalia consist of a cardinal plate possessing a foramen posteriorly and basally supported by a pair of crural plates. The foramen is closed off in large specimens. Cloud (1942, p. 78) mentions the presence of crural plates converging medially about the myophragm in *A. parva* so as to form a structure resembling a cruralium. Similar features have been observed by the writer in small specimens of



TEXT-FIG. 4—*Amphigenia chickasawensis* Boucot, n. sp. Note the impressions on either side of the spondylium of the mystrochial plates. Strata of Onondaga age. 4280–4295 ft., Union Producing Co., Dinsmore No. 1 Well, Sec. 28, T. 12 S., R. 3 E., Chickasaw Co., Miss. U.S.N.M. No. 126212C.



TEXT-FIG. 5—Development of spondylium from medially conjunct dental lamellae in the lineage *Rensselaeria-Etymothyris-Amphigenia*. (mys = mystrochium; myo = myophragm; dl = dental lamellae, ms = median septum composed of conjunct dental lamellae).

A. elongata, *A. parva*, and *A. curta*. Examination of well preserved specimens belonging to *A. curta* shows that his cruralium-like structure is actually formed by the deposition of secondary material between the crural plates so as to raise the tube connecting the floor of the valve with the cardinal plate. Specimens of *A. elongata* from Highland Mills exhibit every gradation from shells with no secondary material on the floor of the valve to those in which the tube is elevated and a cruralium appears to be present. A narrow pair of postero-lateral adductor impressions laterally borders the elongate medial adductor impressions, which are bisected by a myophragm extending under the cardinal plate.

Pedicle interior.—The dental lamellae converge medially to form a spondylium and supporting median septum. The median septum is about twice the length of the spondylium and extends anteriorly from one-third to one-quarter the distance to the anterior margin. The stubby hinge teeth are located on the posterior margins of the spondylium. Postero-laterally the spondylium is buttressed by mystrochial plates.

Comparison.—*A. elongata* is most similar to *A. parva;* however, the greater size reached by many specimens of the former indicates that size may be the criterion for discriminating between the two species. There is a strong possibility that *A. parva* is a synonym of *A. elongata*. *A. curta* has an almost equally biconvex form, the brachial valve being almost as convex as the pedicle valve, whereas in *A. elongata* and *A. parva* the brachial valve is relatively flat compared with the deeply carinate pedicle valve. *A. chickasawensis* possesses relatively flat valves in contrast to all other species belonging to the genus. *A. preparva* lacks a true spondylium in contrast with *A. elongata*.

Kindle and Eidman (1955, p. 184) assigned the large specimens from Highland Mills to *A. elongata* and the small specimens to *A. curta*. The flat brachial valves of the small specimens from Highland Mills preclude their assignment to *A. curta* but not to *A. parva*. The writer, however, concludes that the small specimens belong to *A. elongata* as no basis other than size could be found for discriminating them from the big specimens.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

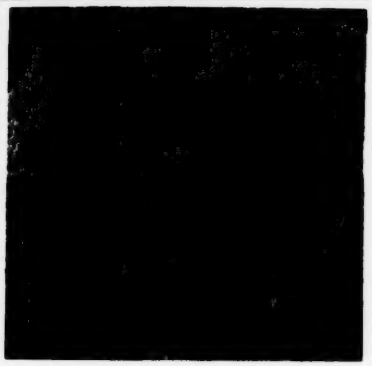
Geologic location.—Kanouse sandstone.

Figured specimens.—U.S.N.M. 126717, 126718, 126718A–D.

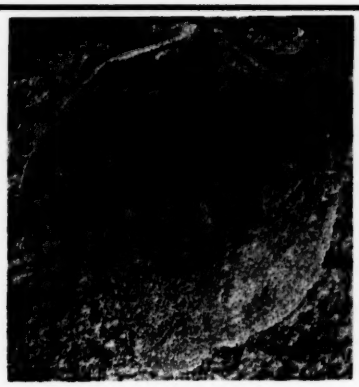
Unfigured specimens.—U.S.N.M. 125919.

EXPLANATION OF PLATE 102

FIGS. *1–11*—*Meganterella finksi* Boucot, n. gen. n. sp. *1*, Latex replica of interior of brachial valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126727; *2*, Latex replica of interior of pedicle valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126726; *3*, Impression of interior of pedicle valve (×1). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126723; *4*, Impression of interior of brachial valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126727; *5*, Impression of interior of brachial valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126724; *6*, Impression of interior of brachial valve (×1). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126729 (holotype); *7*, Latex replica of interior of brachial valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126724; *8*, Impression of interior of brachial valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126728; *9*, Latex replica of interior of brachial valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126725; *10*, Impression of interior of brachial valve (×3). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126725; *11*, Latex replica of exterior of pedicle valve (×2). Highland Mills member of Esopus formation. Railroad cut at Highland Mills, Orange County, New York. U.S.N.M. No. 126726.

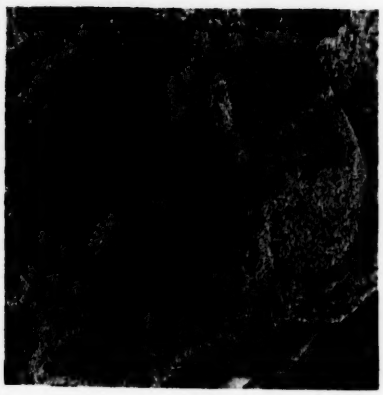


1



2

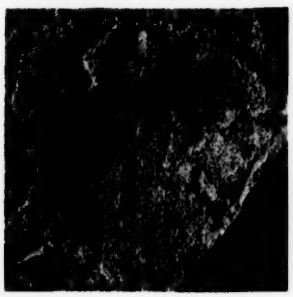
3



4

5

6

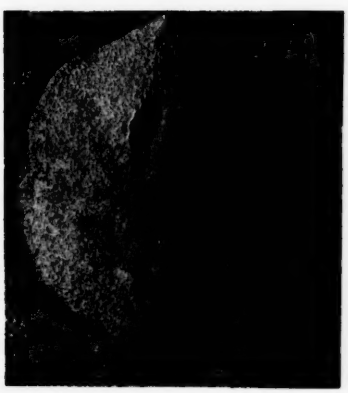


7

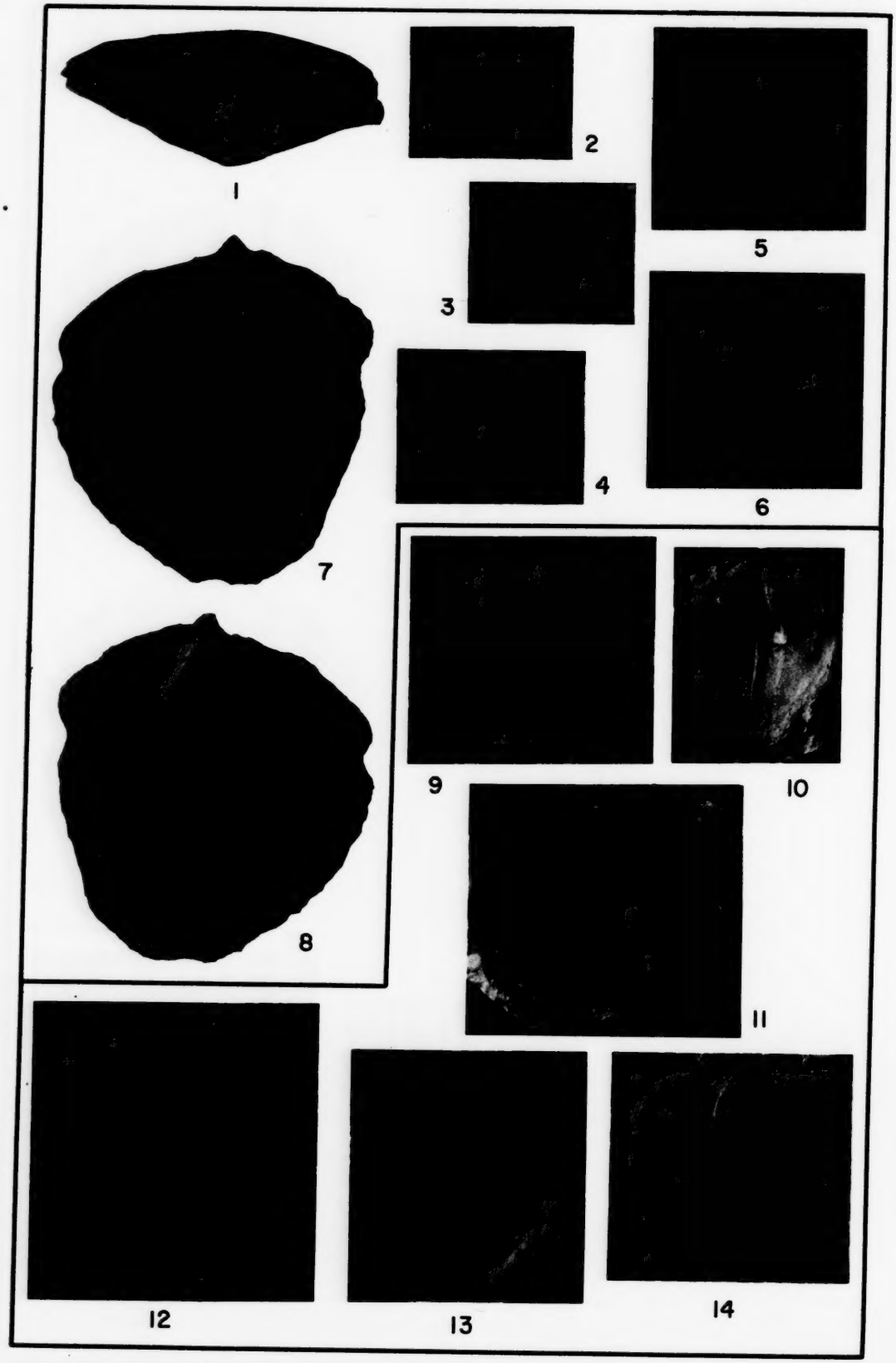
8

9

10



11


1
2
3
4
5
6
7
8
9
10
11
12
13
14

AMPHIGENIA PREPARVA Boucot, n. sp.
Pl. 100, figs. 5–7

Exterior.—Well-preserved exteriors were not found, but the available scraps indicate that the shells are smooth except for concentric growth lines.

Pedicle interior.—The dental lamellae converge medially and either barely meet to form a spondylium or barely fail to meet. A median septum is absent. From internal impressions it is not possible to be certain whether a thin skim of secondary material floors the area medial to the convergent dental lamellae or whether the dental lamellae barely meet. The stubby hinge teeth are located on the posterior margins of the dental lamellae. Posterolaterally the dental lamellae are buttressed by mystrochial plates.

Brachial interior.—The brachial interior is similar in all respects to that of *A. elongata.*

Comparison.—*A. preparva* differs from all other known species of the genus in the absence of a median septum and the presence of convergent dental lamellae which barely meet to form a spondylium, or possibly fail to meet. *A. preparva* has the very long dental lamellae characteristic of *Etymothyris*, but it also has well defined mystrochial plates, a feature known in no other brachiopod but *Amphigenia.* Its stratigraphic position in the lower part of the Woodbury Creek member and the morphology of its pedicle valve shows that *A. preparva* represents a link between *Etymothyris* and *Amphigenia.* Cloud's conclusion (1942, fig. 5) that the Amphigeninae were derived from the Rensselaerinae is thus further substantiated. However, Cloud's conclusion (1942, p. 59) that the lower, marine portion of the Gaspe sandstone, which contains *Etymothyris*, is of Onondaga age receives no support from the evidence available at Highland Mills. Rather, the presence of *Etymothyris* and *Eodevonaria gaspensis*, together with the gradational boundary between the Gaspe sandstone and the Grande Greve limestone below, suggests that the lower, marine portion of the Gaspe sandstone is probably the same age as the Highland Mills member.

Occurrence.—In woods on the west side of the Thruway, near Highland Mills, Orange County, New York.

Geologic location.—Lower part of the Woodbury Creek member of the Esopus formation.

Figured specimens.—U.S.N.M. 126718F, G.

AMPHIGENIA CHICKASAWENSIS Boucot, n. sp.
Pl. 101, figs. 1–3

Exterior.—The shell is unequally biconvex, the carinate pedicle valve being about one and one-half times more convex than the brachial valve. The maximum width is

---

EXPLANATION OF PLATE 103

FIGS. *1–8—Meganteris archiaci* (Verneuil, 1856). *1*, Impression of interior (posterior view, ×1). Beds of Lower Devonian age. Daun, Eifel, Germany. M.C.Z. No. 9414; *2–3*, Impression of interior of brachial valve (×1). Beds of Lower Devonian age. Daun, Eifel, Germany. M.C.Z. No. 9414; *4*, Latex replica of interior of brachial valve (×1). Beds of Lower Devonian age. Daun, Eifel, Germany. M.C.Z. No. 9414; *5*, Latex replica of interior of brachial valve (×1). Beds of Lower Devonian age. Houffalize, Ardennes, Belgium. M.C.Z. No. 9415; *6*, Impression of interior of brachial valve (×1). Beds of Lower Devonian age. Houffalize Ardennes, Belgium. M.C.Z. No. 9415; *7* Impression of interior of pedicle valve (×2). Beds of Lower Devonian age. Daun, Eifel, Germany. M.C.Z. No. 9413; *8*, Impression of interior of brachial valve (×2). Beds of Lower Devonian age. Daun, Eifel. Germany. M.C.Z. No. 9413.

9–14—Reeftonella neozelanica (Allan, 1935). *9*, Latex replica of interior of pedicle valve (×1). Reefton beds. Lankey Creek, Reefton, New Zealand. U.S.N.M. No. 126731; *10*, Latex replica of interior of pedicle valve (×1). Reefton beds. Lankey Creek, Reefton, New Zealand. U.S.N.M. No. 126730; *11*, Latex replica of interior of brachial valve (×1). Reefton beds. Lankey Creek, Reefton, New Zealand. U.S.N.M. No. 126730; *12*, Latex replica of exterior of brachial valve (×1). Reefton beds. Lankey Creek, Reefton, New Zealand. U.S.N.M. No. 126730; *13*, Latex replica of interior of brachial valve (×1). Reefton beds. Lankey Creek, Reefton, New Zealand. U.S.N.M. No. 126730; *14*, Impression of interior of pedicle valve (×1). Reefton beds. Lankey Creek, Reefton, New Zealand. U.S.N.M. No. 126731.

slightly posterior of the mid-length. The outline of the shell is longitudinally elongate and elliptical. The anterior margin is rectimarginate and faintly crenulate. The lateral and anterior margins are rounded. The ornamentation consists of faint costellae on the periphery and concentric growth lines. The cardinal margins are subterebratulid in form.

Pedicle interior.—The dental lamellae are short and converge medially to form a spondylium which is basally supported by a median septum. The underside of the spondylium is posteriorly buttressed by a pair of nearly horizontal mystrochial plates. The stubby hinge teeth are situated on the posterior margins of the spondylium. A bulbous pedicle callist occupies the posterior wall of the delthyrial cavity, and anterior of the callist is a short myophragm. The median septum extends from one-third to one-half the distance to the anterior margin.

Brachial interior.—The cardinalia consist of a posteriorly perforate cardinal plate supported basally by crural plates. The dental sockets are narrow, laterally directed, and situated along the posterior face of the cardinal plate. The muscle field is narrow and extends to about the midlength. It consists of a pair of lateral adductors and a pair of medial adductors which are anteriorly divided by a myophragm.

Comparison.—*A. chickasawensis* may be distinguished from *A. curta*, *A. elongata*, and *A. parva* by its elliptical outline and the gently biconvex mature of its two valves. The pedicle valve is not nearly so deep and carinate as are the pedicle valves of other described species of *Amphigenia*.

Occurrence.—Drill core from depths of 4188′ and 4295′, Union Producing Company's Dinsmore no. 1 Well, sec. 28, T. 12S., R. 3 E., Chickasaw County, Mississippi.

Geologic location.—Strata of Onondaga age. Associated with *A. chickasawensis* are *Odontocephalus* cf. *O. selenurus*, and *Eodevonaria* cf. *E. arcuata*, which are all indicative of an Onondaga age.

Holotype.—U.S.N.M. 123380.

Figured specimen.—U.S.N.M. 126212.

Subfamily MEGANTERINAE Schuchert, 1929, emended

Discussion.—Schuchert's family Meganteridae (Schuchert and LeVene, 1929) is here revised as a subfamily of the Centronellidae. Restudy of *Meganteris* and the allied genus *Meganterella* show that these genera possess crural plates supporting a perforate or imperforate cardinal plate. The only described loop (*Meganteris*) does not correspond to any loop previously described as centronelliform, but until more information is available regarding the reliability of loop types as a function of taxonomic position and of growth stage in an individual shell the writer considers the loop less useful for taxonomic purposes than the character of the cardinalia and pedicle interior.

Diagnosis.—Centronellid brachiopods possessing a posteriorly sessile to wholly sessile cardinal plate in the brachial valve and having sub-triangular hinge teeth in the pedicle valve. The lateral margins are not introverted.

Comparison.—The members of the Meganterinae are closely related to the Eurythyrine, as both have very similar external shape except that the Eurythyrinae have introverted lateral margins. Internally, the Meganterinae have hinge teeth with a subtriangular cross-section, whereas the Eurythyrinae have more blade-like hinge teeth.

Genera Assigned

MEGANTERIS Suess, 1855 (=VLTAVOTHYRIS Havlicek, 1956)

MEGANTERELLA Boucot, new genus

Genus MEGANTERIS Suess, 1855 (=VLTAVOTHYRIS Havlicek, 1956)

Pl. 103, figs. 1–8

Diagnosis.—*Meganteris* possesses a sessile cardinal plate formed from conjunct hinge plates supported by crural plates. There is a ponderous, boss-like cardinal process in large specimens, no cardinal process in small specimens, and a small, posteriorly located cardinal process in specimens of intermediate size. The hinge teeth have a subtriangular cross-section. The muscle field in the pedicle valve is deeply impressed and consists of paired, elongate impressions. The dental lamellae become increasingly obsolete with increase in size due to the deposition of secondary material in the umbonal cavities.

Comparison.—*Meganteris* has largely obsolete dental lamellae, whereas *Meganterella* does not tend to develop obsolete dental lamellae. Havlicek (1956, p. 87) proposed

the genus *Vltavothyris* for *Meganteris*-like terebratuloids possessing crural plates supporting the hinge plates. Havlicek (*op cit.*) concluded, following Cloud (1942), that *Meganteris* lacks crural plates but such is not the case as evidenced by the specimens figured in this paper. Cloud's studies were based entirely on large specimens in which secondary material had completely enveloped the crual plates, whereas Havlicek and the writer had access to small shells. Since none of the characters described for *Meganteris svobodai* (Havlicek, 1956) are inconsistent with an assignment to *Meganteris*, *Vltavothyris* is here placed in the synonymy of the former.

Genus MEGANTERELLA Boucot, n. gen.

Type species.—*Meganterella finksi* Boucot, n. gen., n. sp.

Diagnosis.—The genus *Meganterella* is erected to include meganterinids possessing an undivided and relatively weakly impressed muscle field in the pedicle valve and never developing a bulbous cardinal process in the brachial valve. The dental lamellae do not become obsolete with increase in size of the specimen.

Comparison.—*Meganterella* does not possess increasingly obsolete dental lamellae in increasingly larger specimens, as does *Meganteris*. *Meganterella* has a very weakly impressed muscle field in the pedicle valve as compared to *Meganteris*. *Meganterella* never develops the mound-like cardinal process possessed by *Meganteris*.

Geologic location.—Highland Mills member of the Esopus formation.

Distribution.—Southeastern New York.

Meganterella finksi Boucot, n. sp.
Pl. 102, figs. 1–11

Exterior.—Unequally biconvex shells with the pedicle valve having a greater degree of convexity than the brachial valve. The shells are longitudinally elongate and have an elliptical outline. The lateral and anterior margins are rounded. The anterior commissure is rectimarginate. The exterior of both valves is smooth except for lightly incised concentric growth lines. The beak of the pedicle valve is suberect, and the foramen is mesothyrid in position. The cardinal margins are terebratulid in form.

Pedicle interior.—The dental lamellae are relatively short and confined to the delthyrial cavity. The dental lamellae medially support the hinge tenth which are subtriangular in cross-section. A pair of grooves, situated just below the hinge line, serve to receive the posterior edge of the brachial valve for articulation. The elongate muscle field is weakly impressed and extends anteriorly to a position short of the midlength.

Brachial interior.—The cardinalia consist of a pair of discrete hinge plates which are joined medially by inclined crural plates and fused medially by a deposit of secondary material into a cardinal plate. The site of the pedicle foramen is occupied by a low pit posterior to which in larger specimens is a small, crescent-shaped cardinal process similar to that seen in small specimens of *Meganteris*. The hinge plates laterally overlap the dental sockets. The deeply impressed muscle field is restricted to the posterior half of the valve and consists of elongate, paired adductor impressions separated by a broad, median septum which posteriorly is fused with the cardinalia. The muscle field may be grooved by transverse furrows as in some specimens of *Mendathyris*.

Occurrence.—Highland Mills, Orange County, New York.

Geologic location.—Highland Mills member of the Esopus formation.

Holotype.—U.S.N.M. 126729.

Figured specimens.—U.S.N.M. 126725–126728.

Unfigured specimens.—U.S.N.M. 125915.

Subfamily CENTRONELLINAE Waagen, 1882

Genus CENTRONELLA Billings, 1859
CENTRONELLA sp.
Pl. 101, figs. 7–9

Exterior.—The shells are small, none over one centimeter being observed. The brachial valve is flat or slightly concave; the pedicle valve is strongly convex and naviculate in form. The maximum width is slightly anterior of the midlength. The anterior and lateral margins are rounded. The anterior commissure is rectimarginate. The beak characters could not be discerned in the available material. The shell is smooth.

Brachial interior.—The cardinalia consist of massive hinge plates medially separated by a deep groove. The muscle field is not

visible on the material studied. The interior is smooth.

Pedicle interior.—Short, almost obsolete dental lamellae bound the cordate muscle field. The hinge teeth are stubby, and much secondary material fills the umbonal cavities. A narrow myophragm bisects the posterior portion of the muscle field. The interior is smooth.

Occurrence.—Railroad cut at Highland Mills, Orange County, New York.

Geologic location.—Kanouse sandstone.

Figured specimens.—U.S.N.M. 126264A–C.

Family DIELASMATIDAE Schuchert, 1929
Subfamily CRANAENINAE Cloud, 1942
Genus REEFTONELLA Boucot, n. gen.
Pl. 103, figs. 9–14

Type species.—*Meganteris neozelanica* Allan, 1935, Wellington Geol. Surv., Paleont. Bull., No. 14, p. 23–24, pl. 2, figures 9,10; pl. 3, figures 3 and 5.

Diagnosis.—Dielasmatid brachiopods with deeply incised concentric growth lines, and a sessile cardinal plate in the adult.

Comparison.—*Reeftonella* may be distinguished from *Meganteris* because it lacks a cardinal process or crural plates and has very deeply incised growth lines. *Meganteris* has a cardinal process and weakly incised growth lines. The presence of a sessile cardinal plate distinguishes *Reeftonella* from *Cranaena*. It differs from *Hamburgia* in the presence of a cardinal plate with an open foramen.

REEFTONELLA NEOZELANICA (Allan, 1935)
Pl. 103, figs. 9–14

Meganteris neozelanica Allan, 1935; Wellington Geol. Surv., Palaeont. Bull., no. 14 p. 23–24, pl. 2, figs. 9,10; pl. 33, figs. 3 and 5.

Beachia neozelanica (Allan, 1935); Jour. Paleon., vol. 21, no. 5, p. 449–450, pl. 63, figs. 1–3, 1947.

Exterior.—Subequally biconvex, the pedicle valve having the greater convexity, pedicle foramen mesothyrid, anterior margin rectimarginate, cardinal margin terebratulid, pedicle beak suberect. Greatest width just anterior of the hinge line, outline subcircular to shield-shaped. Ornamentation consists of deeply incised concentric growth lines. Both the lateral and anterior margins are rounded. The cardinal margin is terebratulid and the beak of the pedicle valve is suberect. The shells do not possess introverted lateral margins. The deltidial plates are medially conjunct.

Pedicle interior.—Dental plates obsolete in large specimens, massive hinge teeth with triangular cross-section (apex of triangle pointing anteriorly), muscle field deeply impressed and consisting of paired elongate-cordate diductor impressions separated by a rounded median ridge which extends two-thirds of the distance to the anterior margin; posterior portion of median septum bears a short septum which bisects the elongate and weakly impressed adductor impressions. Posterior portion of delthyrial cavity is explained to enclose the pedicle callist. Posterior to the hinge teeth in large specimens are grooves paralleling the hinge line, which serve to receive the posterior edge of the brachial valve.

Brachial interior.—The cardinalia consist of a perforate, sessile cardinal plate. The perforation in the cardinal plate is sealed off in very large specimens, leaving only a pit at the posterior portion of the plate. The dental sockets are laterally diverging, and the deeply impressed adductor muscle field is bisected by a median septum. The loop is unknown.

Geologic location.—High Lower Devonian (Siegenian).

Figured specimens.—U.S.N.M. 126730–126731.

Fossil Localities

The Central Valley sandstone was collected at the west side of the Thruway cut in the town of Highland Mills.

The Connelly conglomerate was likewise collected only at the west side of the Thruway cut in the town of Highland Mills.

The Highland Mills member of the Esopus formation was collected only in the railroad cut in the town of Highland Mills. The fossils occur both in scattered lenses of shell debris and as scattered shells on the bedding planes of the sandstone.

The middle member of the Esopus formation contains only abundant *Taonurus* and was not collected.

The Woodbury Creek member of the Esopus formation is well exposed along the railroad tracks and immediately west of the

Thruway in the woods east of the railroad. Fossils were collected in both places.

The Kanouse sandstone is exposed in the woods between the railroad tracks and the Thruway where a curve brings the railroad tracks to within about 50 yards of the Thruway. This locality is about three quarters of a mile north of the beginning of the railroad cut at the abandoned Highland Mills railroad station, about half a mile beyond the railroad cut.

LITERATURE CITED

ALLAN, ROBIN, 1947, A revision of the brachiopods of the Lower Devonian strata of Reefton, New Zealand: Jour. Paleontology, v. 21, no. 5, p. 436–452.

BOUCOT, A. J., 1957, Position of North Atlantic Silurian-Devonian Boundary (abstract): Geol. Soc. America, Bull., v. 68, pt. 2, p. 1702.

—— & CUMMING, L. M., 1953, Age of the Gaspe sandstone (abstract): Geol. Soc. America, Bull., v. 64, p. 1397.

CHADWICK, G. H., 1908, Revision of "The New York series": Science, new ser., v. 28, p. 346–348.

CLARKE, J. M., 1907, Some New Devonic Fossils: N. Y. State Mus. Bull. 107.

CLARKE, J. M., 1909, Early Devonic History of New York and Eastern North America, pt. 2: N. Y. State Mus., Mem. 9, 250 p.

CLOUD, P. E., JR., 1942, Terebratuloid brachiopods of the Silurian and Devonian: Geol. Soc. America, Sp. Paper No. 38, 182 p.

COOPER, G. A., ET AL., 1942, Correlation of the Devonian Sedimentary Formations of North America: Geol. Soc. America, Bull., v. 53, p. 1729–1794.

DARTON, N. H., 1894A, Geologic relations from Green Pond, New Jersey to Skunnemunk Mountain, New York: Geol. Soc. America, Bull., v. 5, p. 367–394.

——, 1894B, 13th Ann. Rept., N. Y. State Geol. Survey, p. 209–302.

GOLDRING, W., 1943, Geology of the Coxsackie quadrangle, New York: N. Y. State Mus., Bull., no. 352, 374 p.

GRABAU, A. W., 1903, Stratigraphy of Becraft Mountain, Columbia County, New York: N. Y. State Mus. Bull., no. 69, p. 1030–1079.

HAVLICEK, V., 1956, The brachiopods of the Branik and Hlubocepy limestones in the immediate vicinity of Prague: Sbornik Ustredniho Ustavu Geologickeho, SV. XXII, 131. p.

KINDLE, C. H. & EIDMAN, S. H., 1955, Fauna of the Kanouse sandstone at Highland Mills, New York: Jour. Paleontology, v. 29, no. 1, p. 183–185.

KUMMEL, H. B., 1908, Description of the Franklin Furnace quadrangle, New Jersey: U. S. Geol. Survey Folio No. 161, 27 p.

SCHUCHERT, C. & LEVENE C. M., 1929, Brachiopoda. Fossilium Catalogus, W. Junk, Berlin, 140 p.

WELLER, S., 1903, The Paleozoic Faunas, Geol. Survey, N. J., v. 3, 462 p.

MANUSCRIPT RECEIVED OCTOBER 9, 1958.

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 770–792, PLS. 104–107, 2 TEXT-FIGS., SEPTEMBER, 1959

EARLY PENNSYLVANIAN FUSULINIDS AND OSTRACODS OF THE ILLINOIS BASIN

M. L. THOMPSON, R. H. SHAVER, AND E. A. RIGGS
Illinois Geological Survey, Indiana Geological Survey, and University of Illinois

ABSTRACT—Fusulinids are described or illustrated from an unnamed limestone near Morgantown, Butler County, Kentucky; from the Curlew limestone of Union and Crittenden counties, Kentucky; from the Boskydell? marine zone of the Delwood sandstone of Pope County, Illinois; and from a limestone considerably above the Delwood sandstone in Saline County, Illinois. They include *Profusulinella kentuckyensis*, n. sp., and numerous unnamed forms of *Millerella* and *Paramillerella* from near Morgantown; *Fusulinella stouti* and *F. iowensis* from the Curlew limestone; *Fusulinella stouti?* from the *Boskydell?* marine zone; and *Fusulina serotina* and *F.* aff. *F. leei* from the limestone of Saline County.

This first observation of *Profusulinella* east of the Mississippi River demonstrates the presence of lower Derryan (lower Atokan) rocks in central Kentucky. The presence of numerous associated ozawainellids, such as *Millerella* spp. and *Paramillerella* sp., supports the interpretation that the containing rocks are of lower Middle Pennsylvanian age. The most primitive Pennsylvanian marine rocks that can be identified at the present time in the Illinois Basin are in the eastern part of the Basin in Kentucky and Indiana.

The ostracods described or illustrated from the limestone near Morgantown include four new, three previously described, and one unnamed form of *Bairdia;* four previously described forms of *Fabalicypris;* one unnamed form of *Basslerella;* one new species each of *Healdia* and *Aurikirkbya;* and one previously known form of *Amphissites.* They compare closely with the ostracods known from the lower part of the Dornick Hills group of the Ardmore Basin, Oklahoma.

INTRODUCTION

FUSULINIDS have been reported from Pennsylvanian rocks of Illinois for about 100 years but only two publications have been devoted to them. The first of these was a description of a fauna from one marine interval, and a few specimens from another interval, by Henbest in 1928. The second was a comprehensive treatment by Dunbar & Henbest (1942) of all Pennsylvanian fusulinids known at that time in Illinois, and of a few faunas from immediately adjacent regions. The larger fauna described by Dunbar & Henbest was obtained from 16 marine intervals in the State, ranging in age from the oldest known at that time (Boskydell? marine zone) up to the Greenup limestone. Although the fusulinids studied were from only 16 marine intervals, at least 24 additional intervals in the Pennsylvanian of Illinois were known to contain invertebrate marine fossils. Several additional marine intervals have been recognized in the Illinois Basin since that time.

Members of the Family Fusulinidae have been demonstrated in many localities in America, and in numerous other parts of the world, to be among the very best known fossils for detailed correlation and age determination of marine rocks in the Pennsylvanian and Permian systems. From studies of the fusulinids and other evidence, it seemed almost sure that the Pennsylvanian rocks of the Illinois Basin include most all larger elements of the Desmoinesian, Missourian, and Virgilian series as defined in other areas but that the basal units of the system present in different parts of the Basin probably are not of the same age. Furthermore, it seemed unlikely that so many typical marine rocks in the Pennsylvanian of Illinois do not contain fusulinids. With those factors in mind, Dr. John C. Frye, Chief, Illinois Geological Survey, suggested to the senior author of this report in 1954 that it was timely to re-investigate the Pennsylvanian fusulinid fauna of Illinois.

It seemed best to start this study by defining on faunal evidence the relative ages of the oldest Pennsylvanian marine fossil-bearing rocks around the margins of these strata. In the meantime, Shaver had started a study of the Pennsylvanian ostracods of Indiana, and we decided to join efforts by

combining a study of the lower Pennsylvanian fusulinids and ostracods of the Illinois Basin.

In the immediate preceding interval of time, Riggs had made an extensive search of the Pennsylvanian in the southern part of the Illinois Basin in Kentucky for fusulinids to be incorporated in his Master's thesis at the University of Wisconsin. Riggs obtained fusulinids from near the base of the Pennsylvanian in Butler and Union counties, Kentucky. Thompson and Shaver also collected and studied fusulinids and ostracods in the same parts of the section. Furthermore, unstudied fusulinids from the lower part of the Pennsylvanian of southern Illinois are in the Illinois Geological Survey collection.

Riggs visited numerous outcrops of Pennsylvanian rocks in Kentucky and examined many test cores of coal companies from various parts of the State. Thompson and Shaver started their studies along the southern margin of the Pennsylvanian rocks in Kentucky, southern Indiana, and Illinois in an attempt to determine the most primitive elements of marine and fossil-bearing Pennsylvanian rocks in the Basin, for they assumed, as many others had, that early Pennsylvanian marine invasions were from a southerly direction. They soon realized that they were duplicating, in part, work previously done by Riggs, and they decided to combine efforts in this preliminary statement regarding faunal evidence of the ages of the lower Pennsylvanian limestones in the southern part of the Illinois Basin.

This preliminary report concerns fusulinids and ostracods from western Kentucky and southeastern Illinois (text-fig. 1). Publication is authorized by the Chief, Illinois Geological Survey, and the State Geologist, Indiana Geological Survey. All fusulinids are deposited with the Illinois Geological Survey under the catalogue number 13P. The repository for all ostracods is indicated in the text of Part II.

PART I. PRIMITIVE FUSULINIDS IN THE SOUTHERN PART OF THE ILLINOIS BASIN

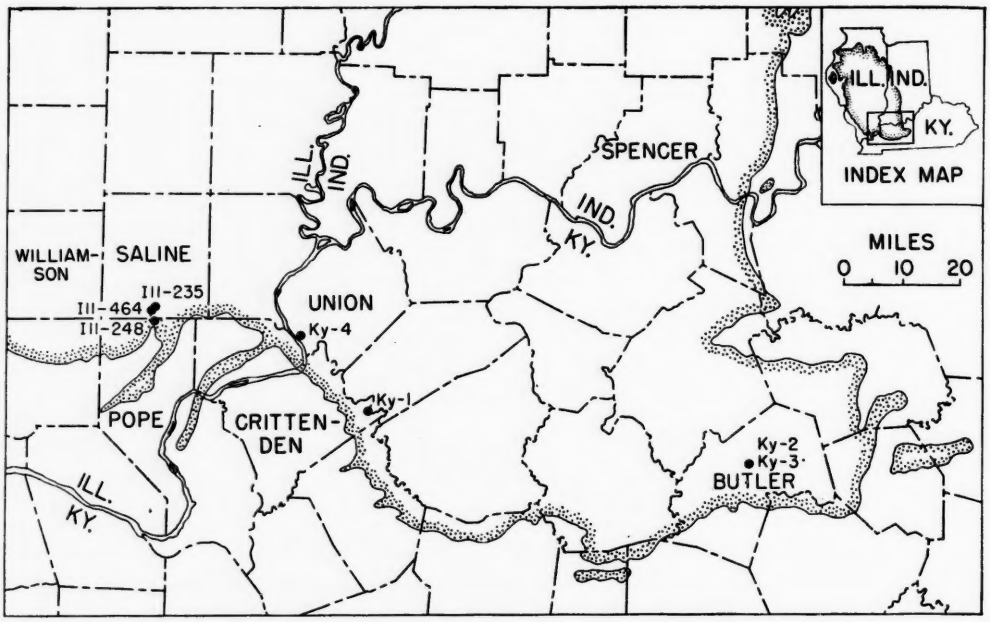
M. L. THOMPSON AND E. A. RIGGS

THE most primitive fusulinid that Dunbar & Henbest described from the Illinois Basin was obtained from a calcareous and fossiliferous bed within what was questionably assigned to the Boskydell sandstone in Pope County of southern Illinois. From this they identified *Fusulinella iowensis* var. *stouti* Thompson. This variety was also identified by them from the Seville limestone of northwestern Illinois.

They described as *Fusulina leei* Skinner common specimens from higher in the section of southern Illinois in a limestone identified as Curlew limestone. It has been the common opinion for many years that the Curlew limestone of Kentucky and southern Illinois is the time equivalent of the Seville limestone of northwestern Illinois that contains a fusulinid fauna of *Fusulinella iowensis*, *F. iowensis* var. *stouti*, and *F. gephyrea*. Dunbar & Henbest expressed surprise that the Curlew of southern Illinois has a considerably more advanced fauna of *Fusulina* if it is of the same age as the Seville limestone of northwestern Illinois which has forms of *Fusulinella*.

Riggs, and later Thompson and Shaver, visited the type section of the Curlew limestone on Indian Hill in Union County, Kentucky, and obtained well preserved collections described below as *Fusulinella iowensis*. Also, *Fusulinella stouti* is illustrated below from the limestone exposed in Crittenden County on the north road bank of Kentucky Highway 120, 5.3 miles west of Providence (Ky-1). We examined a large number of exposures of the limestone in Saline County, Illinois, that had been identified as Curlew limestone, and obtained from it great numbers of fusulinids illustrated below as *Fusulina serotina* (Thompson) (Pl. 106, figs. 29–33) and *F.* aff. *F. leei* Skinner (Pl. 106, figs. 25–28).

A sample in the Illinois Geological Survey, obtained by J. M. Weller in 1926, is labeled as being from the same locality of the



TEXT-FIG. 1—Outline map showing locations of collections studied. Stippled boundary indicates margin of Pennsylvanian outcrop.

Boskydell marine zone as that from which Dunbar & Henbest identified and illustrated *Fusulinella iowensis* var. *stouti* from Pope County. We are describing and illustrating a fusulinid from this sample as *Fusulinella stouti*?.

No fusulinid had been described or illustrated from the lower part of the Pennsylvanian in western Kentucky prior to 1951. The only references to fusulinids in this region are listings on a few occasions along with general faunal groups. The search by Riggs during 1951 and 1952 has demonstrated the presence of fusulinids at a number of places and through great thicknesses of the Pennsylvanian in western Kentucky. The most primitive of these is from the north valley wall of Green River about a mile north of Morgantown, Butler County, where great numbers of *Profusulinella kentuckyensis*, new species, and numerous forms of *Millerella* and *Paramillerella* are found in the thin limestones and associated shales on the northwest cut bank of U. S. Highway 231. Thompson and Shaver collected from these limestones in 1957 and measured the section described below under "Collection Localities."

The most primitive fusulinid fauna so far observed in the southern part of the Illinois Basin is that found near Morgantown in Butler County, Kentucky. This locality is near the southeastern margin of the area of Pennsylvanian rocks.

The second most primitive fusulinid fauna is that in the questionable Boskydell of Pope County, Illinois, and the third most primitive is that from the Curlew type section of Union County and from the Curlew in Crittenden County, Kentucky.

The fourth most primitive fauna we have observed along this southern margin is that from the limestone formerly reported as Curlew limestone in Saline County of southern Illinois. It is evident that this latter limestone is considerably younger than the Curlew limestone at its type locality in Kentucky. We are illustrating the fusulinids from it as *Fusulina serotina* (Thompson) and *F.* aff. *F. leei* Skinner. It seems that this limestone is without a formal name.

STRATIGRAPHIC SUMMARY OF THE FUSULINIDS

Zone of *Profusulinella*.—The genus *Profusulinella* Rauser-Cernoussova & Beljaev

was established for Eurasian fusulinids in 1936 and has since been observed at numerous places in North America. It is one of the first of the fusiform fusulinids and possibly was derived from some member of Schubertellinae, and probably from *Eoschubertella*. All available evidence indicates that *Profusulinella* is the ancestral stock of *Fusulinella*. The two genera have not been observed in direct association, and they have not been demonstrated to overlap stratigraphically. Species of *Profusulinella* are exceedingly abundant in many areas throughout the lower part of the Derryan Series and that part of the section is referred to as the Zone of *Profusulinella*. Representatives of the genus have been recognized over wide areas in America, including such widely separated localities as north-central Texas, extreme western Texas, southern New Mexico, western Utah, eastern Nevada, eastern Wyoming, and southern Oklahoma. In most all of the above mentioned localities, it can be demonstrated that *Profusulinella* occurs there either in the basal part of an overlapping series of rocks of Middle Pennsylvanian age and unconformably above Morrowan rocks of the Lower Pennsylvanian or unconformably above still older rocks.

St. Jean (1957) reports *Profusulinella fittsi* (Thompson) in association with six other species of fusulinids in the Staunton formation of eastern Indiana, including the Desmoinesian fusulinids he identified as *Fusulina novamexicana* Needham, *F. haworthi* (Beede), and *Wedekindellina euthysepta* (Henbest). His illustrations are drawings. We restudied St. Jean's original specimens, as well as additional collections obtained from the same locality, but have been unable to identify *Profusulinella*.

We obtained abundant fusulinids from the limestone exposed on the north bank of Green River above U. S. Highway 281 about a mile north of Morgantown, Butler County, Kentucky, that are being described below as *Profusulinella kentuckyensis*, new species. Although this species is considerably different from all other American species of the genus, it is a true form of *Profusulinella* and would suggest that the rocks from which it came are of the oldest fusulinid-bearing Pennsylvanian rocks so far observed east of the Ozark Uplift.

It has been considered generally that marine invasions into the Illinois Basin were from the south or southwest. However, *Profusulinella* has not been observed previously in any rocks more closely situated than southern Oklahoma. The isolated occurrence of lower Middle Pennsylvanian rocks in southern Missouri (Thompson, 1953) contains *Fusulinella* that are interpreted to be among the earlier species of the genus. Isolated Pennsylvanian limestones in sink holes and depressions in the Mississippian limestones below have been observed near the Mississippi River in eastern Missouri, but the most primitive fusulinids seen in them are of lower Desmoinesian age. Furthermore, primitive Pennsylvanian limestones have not been observed in western Kentucky or in southern Illinois that can point to a route of invasion of the Pennsylvanian from the west or southwest.

Associated with *Profusulinella kentuckyensis* near Morgantown, Kentucky, are abundant and varied faunas of the primitive ozawainellid genera *Millerella* and *Paramillerella* (Pl. 106, figs. 1–24). It should be mentioned that abundant faunas of similar primitive fusulinids are found in association with *Profusulinella* in practically all localities so far studied in Europe and in North America. Although the ozawainellid fauna does not aid greatly in long range correlations or age determinations of rock units, their abundance here does help to substantiate the conclusion that these are considerably more primitive Pennsylvanian marine rocks than were formerly known from this area, except for the report by Cooper of primitive Pennsylvanian ostracod faunas in Indiana (1946).

Zone of *Fusulinella*.—The genus *Fusulinella* Möller was originally described from Russia in 1877. The first American form of the genus was described in 1931 by Skinner but was referred to another genus. Since that time, *Fusulinella* has been described from many areas in the United States and in British Columbia. All available evidence indicated that *Fusulinella* is restricted in America to rocks of Middle Pennsylvanian age. It occurs most commonly in rocks of pre-Desmoinesian and earliest Desmoinesian ages. The single described exception to this statement is the form from eastern Nevada described in 1956 by Verville, Thompson, &

Lokke as *Fusulinella alta* in association with *Fusulina weintzi* V., T., & L. and *Bartramella bartrami* V., T., & L. *Fusulinella* seems to range up into rocks at least as young as the middle Desmoinesian in eastern Nevada. Some occurrences of *Fusulinella* have been reported in the literature as extending up into rocks of Leonardian age, but most, if not all, of these extended upper ranges have been found to have reference to the occurrences of the genus *Pseudofusulinella* Thompson, 1951.

In regions where almost continuous deposits of marine carbonates of Middle Pennsylvanian age are preserved, it can be demonstrated that the structural change from *Profusulinella* to *Fusulinella* was very gradual among such late forms of *Profusulinella* as *P. spicata* and *P. apodacensis* to early *Fusulinella* as *F. fugax*, *F. searighti*, *F. velmae*, and *F. proxima*.

The nearest geographic occurrence of early *Fusulinella* to the Illinois Basin is the primitive *Fusulinella*, *F. searighti* and *F. clarki*, in the Burgner formation (Searight & Palmer, 1957) in Jasper County, Missouri (Thompson, 1953).

Dunbar & Henbest described *Fusulinella iowensis*, *F. iowensis stouti*, and *F. gephyrea* from the Seville limestone of northwestern Illinois and identified the second of these with question in the Boskydell? marine zone of Pope County, Illinois. *F. iowensis* and *F. stouti* had been described previously from the Mercer and Boggs limestones of Ohio, and *F. iowensis* was known in the basal part of the type Desmoinesian section of Iowa. All three of these are advanced forms of the genus and are considered rather typical of lowermost Desmoinesian rocks.

The occurrence of *Fusulinella iowensis* in the type section of the Curlew limestone of Kentucky indicates rather clearly that this part of the Kentucky section is near the same age as the Seville limestone of northwestern Illinois and the basal portion of the Desmoinesian section in Iowa. Rocks of lower Desmoinesian age are among the most widespread of the Pennsylvanian rocks in North America. However, from early Derryan to middle Desmoinesian times, the Pennsylvanian seas were gradually transgressing older Paleozoic rocks in many American regions, and even onto pre-Cambrian rocks in some regions, followed by a general recession to near the end of the Desmoinesian, the greatest transgression occurring near the beginning of Marmaton time.

Zone of *Fusulina*.—The fusulinids we have obtained from the unnamed limestone, formerly called Curlew limestone, of Saline County, Illinois, are referable to *Fusulina* and are illustrated below as *F. serotina* and *F.* aff. *F. leei*. The first of these is a primitive *Fusulina* that was first reported from the Putnam Hill limestone in Ohio. The second was referred by Dunbar & Henbest to *Fusulina leei* Skinner, a form that is widespread in lower Desmoinesian rocks west of the Mississippi River.

COLLECTION LOCALITIES

Illinois

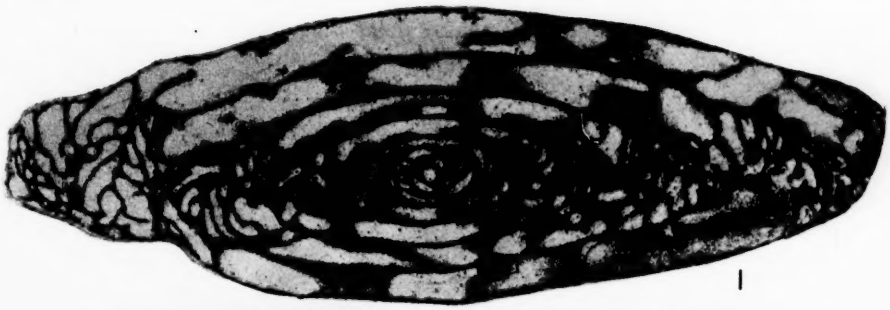
Ill–235. *Unnamed limestone.* Limestone at old roadway, near center of south line of SW¼ sec. 22, T. 10 S., R. 6 E., Saline County, Harrisburg Quadrangle.

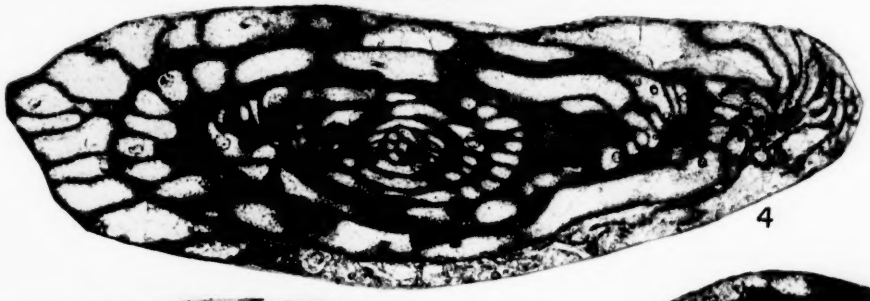
Ill-248. *Boskydell? marine zone.* Highly fossiliferous limestone in thick sandstone exposed in sharp north-south valley and 200

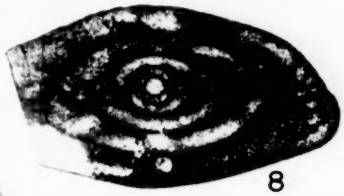
Explanation of Plate 104

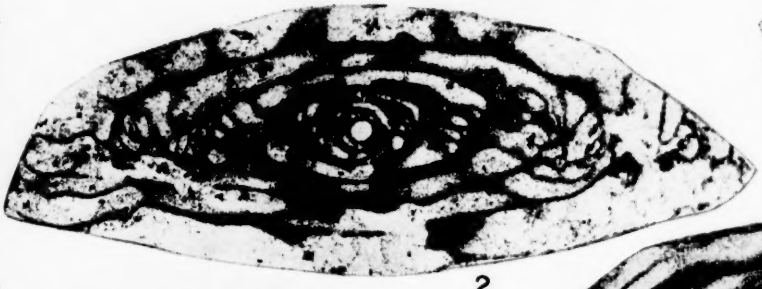
All illustrations on this plate are unretouched photographs. *5–7* and *14* are magnified ×10, and all others are magnified ×40.

Figs. *1–15*—*Profusulinella kentuckyensis* Thompson & Riggs, n. sp. *1*, Axial section of the holotype; *2,3,5–8,10,11*, axial sections of paratypes; *4*, slightly tangential section of a paratype showing wall structure and septal fluting; *9*, slightly tangential section of a short specimen which has unusually heavy chomata; *12–14*, sagittal sections of paratypes; and *15*, tangential section of a paratype showing septal fluting. Specimens of *3,5,6,11,14*, and *15* are from Collection Ky-2, and all others are from Ky-3.


1


4

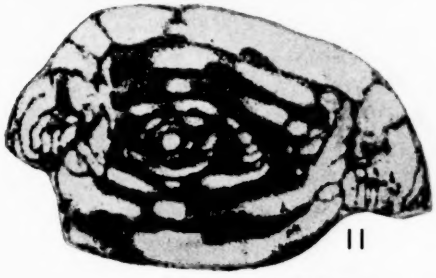

8


2

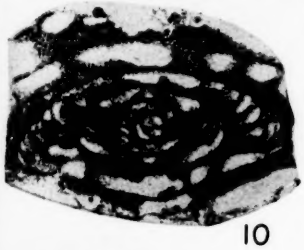
3

15

14

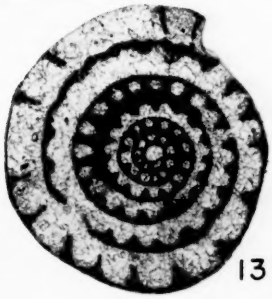

11

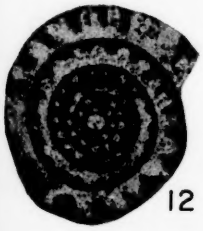
5


10

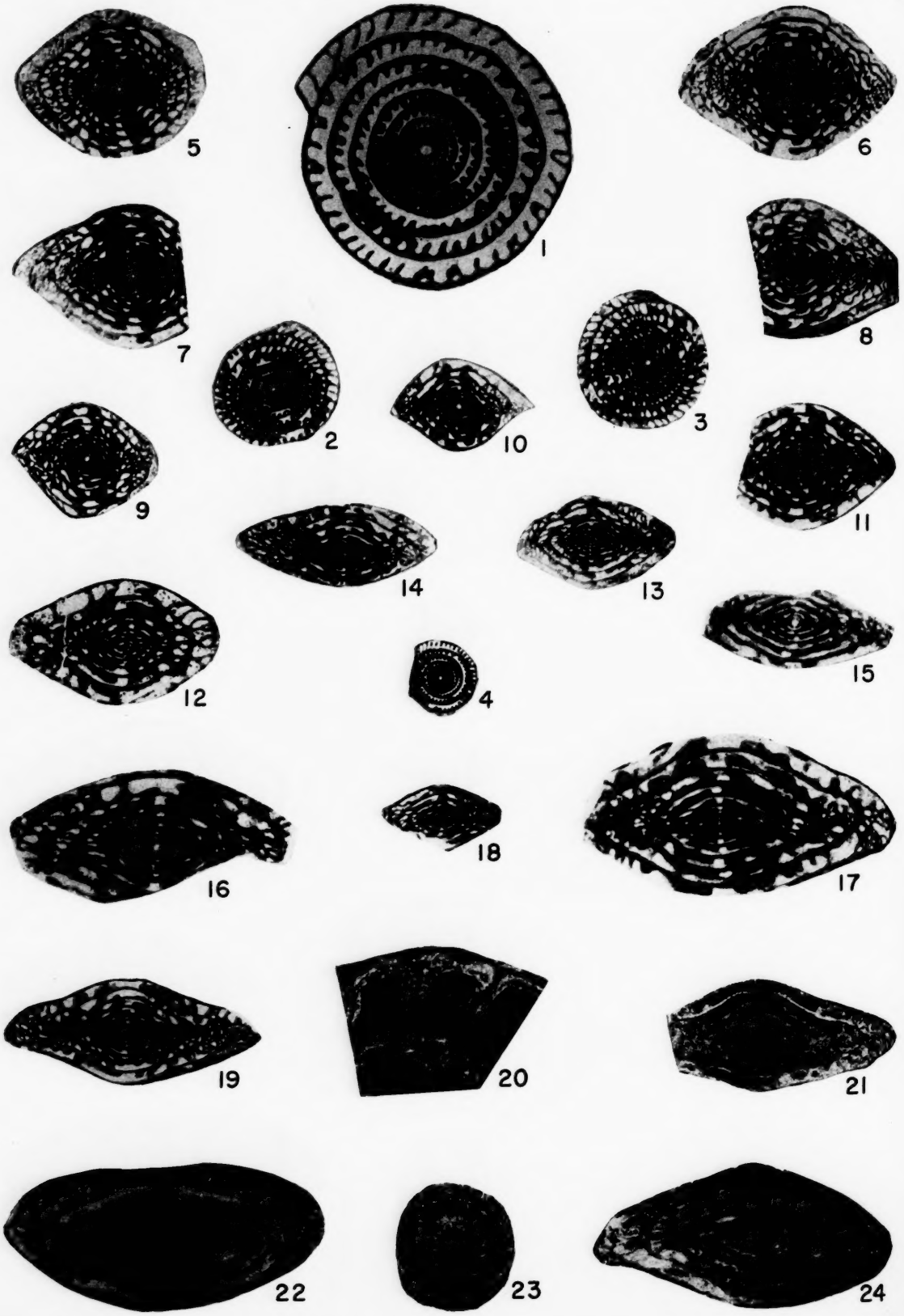
6

7


13


12

9


5
1
6
7
8
2
3
10
9
11
14
13
12
4
15
16
18
17
19
20
21
22
23
24

Bed No.	Description	Thickness (feet)
10	Covered, soil	
9	Shale; olive drab, silty, micaceous, fissile; shale, dark gray, carbonaceous, clayey; with limonitic laminae	16.5
8	Limestone; mottled gray, brown, and olive drab, fossiliferous, dense and hard to crystalline and friable, thin to medium bedded; with shaly break in middle. *Ky-3*	3.9
7	Shale; olive drab, finely micaceous and silty; with few limonitic laminae	7.9
6	Limestone; orange-brown, ferruginous, badly weathered, dense, argillaceous and shaly bedded to crystalline, rubbly, and fossiliferous. *Ky-2*	1.7
5	Shale; dark gray, fossiliferous, clayey, with limestone nodules. *Ky-2*	0.7
4	Limestone; orange-brown, ferruginous, weathered, crystalline, rubbly. *Ky-2*	0.4
3	Shale; dark gray, carbonaceous and green, clayey, with conchoidal fracture	10.8
2	Siltstone; light gray, micaceous, shaly; grading to clay shale above	3.2
1	Sandstone; buff, weathering orange-brown, fine-grained, friable, shaly to medium-bedded, with limonitic laminae; makes bench on west side of road	7.1
Road level at about 480 feet altitude		52.2

yards upstream, south, from farm crossing of stream, exposed on stream bed and banks, a few hundred feet stratigraphically above old coal mine working, NE¼ sec. 4, T. 11 S., R. 6 W., Pope County, Harrisburg Quadrangle.

Ill-464. *Unnamed limestone.* Limestone exposed in pasture west of north-south gravel road, NW¼ sec. 27, T. 10 S., R. 6 E., Saline County, Harrisburg Quadrangle.

KENTUCKY

Ky-1. *Curlew limestone.* Obtained from the lower part of 10 feet of limestone in Crittenden County exposed on the north side of Kentucky Highway 120, 5.3 miles west of Providence.

Ky-2. *Unnamed limestone.* Obtained from the lower of two limestones exposed in the western cut bank of U. S. Highway 231 on the north bluff of Green River and about a mile north of Morgantown. Beds 4, 5, and 6 of section described below.

Ky-3. *Unnamed limestone.* Obtained from the same location as above, but from the upper of the two limestones exposed in the highway cut. Bed 8 of section described below.

Section in road cut, west side of U. S. Highway 231, just north of Green River bridge and one mile north of Morgantown, Morgantown Quadrangle, Butler County, Kentucky.

Ky-4. *Curlew limestone.* Limestone exposed on the southwest side of Indian Hill near its highest point, one mile south of Curlew, one mile southwest of DeKoven, DeKoven Quadrangle, Union County, about 45 feet below the base of the Curlew sandstone that caps the top of Indian Hill.

MILLERELLA spp.
Pl. 106, figs. 1–16

Great numbers of *Millerella*, associated with abundant *Profusulinella kentuckyensis*, n. sp., and *Paramillerella* sp., occur in the two limestones exposed about a mile north of Morgantown, Kentucky. They seem to

EXPLANATION OF PLATE 105

All illustrations on this plate are unretouched photographs, *1,12,15–17*, and *21–24* are magnified ×20, *20* is magnified ×100, and all others are magnified ×10. *1–11* are from Collection Ky-4, *12–19* are from Ky-1, and *20–24* are from Collection Ill-248.

FIGS. *1–11—Fusulinella iowensis* Thompson. *1–4*, Sagittal sections; and *5–11*, axial sections.
12–19—Fusulinella stouti Thompson. *12,13,17,18*, Tangential sections; and *14–16,19*, axial sections.
20–24—Fusulinella stouti Thompson? *20*, Enlarged part of *23* showing *Fusulinella*-type spirotheca; *21,22,24*, axial sections; and *23*, sagittal section.

represent a wide variety of forms, many of which possibly are unnamed. Although it does not seem advisable to propose names for all of them at this time, we are illustrating some of the more common types to present the general variety present in these limestones in association with the species of *Profusulinella*. Some of these specimens possess the largest proloculus observed in comparison to shell size of any of the fusulinids (Pl. 106, fig. 1). There are all variations from partly evolute specimens closely similar to *M. marblensis* to almost completely involute specimens like *M. pressa*.

Occurrence.—Specimens illustrated as *Millerella* spp. are from both the lower and upper limestones exposed on the northwest side of U. S. Highway 231 on the northern bank of Green River a mile north of Morgantown, Kentucky (Ky-2, Ky-3).

PARAMILLERELLA sp.
Pl. 106, figs. 17–24

Numerous specimens are present in association with *Millerella* spp. and *Profusulinella kentuckyensis* that are completely involute and have relatively longer axes of coiling than typical *Millerella*. All of these specimens resemble *Paramillerella advena* more closely than any other type species and are here referred to the genus *Paramillerella*. In some parts of the limestone, specimens are so abundant that several occur on a single thin section (Pl. 106, fig. 23).

Occurrence.—Specimens here referred to *Paramillerella* sp. are abundant in association with specimens of *Millerella* and *Profusulinella kentuckyensis* in the upper and lower fossiliferous limestones and shales on the north side of Green River north of Morgantown, Kentucky (Ky-2, Ky-3).

PROFUSULINELLA KENTUCKYENSIS
Thompson & Riggs, n. sp.
Pl. 104, figs. 1–15

The shell of *Profusulinella kentuckyensis* is small and highly elongate fusiform in shape; with a straight to slightly shifting axis of coiling, broadly convex to irregular or con-

MEASUREMENTS OF *PROFUSULINELLA KENTUCKYENSIS*, N. SP., IN MILLIMETERS

Specimen	L.	W.	Ratio	Vol.	Diam. prol.	Height of volutions					
						1	2	3	4	5	6
1	2.15	0.78	2.8	4	.092	.033	.066	.072	.086	.107	—
2	1.95	0.68	2.9	4	.086	.020	.057	.097	.104	—	—
3	1.65	0.63	2.6	4	.095	.021	.044	.070	.069	.100	—
4	2.39	0.89	2.7	6	.086	.025	.042	.055	.087	.088	.143
5	—	0.63	—	4	.082	.035	.045	.072	.094	—	—
6	—	0.70	—	5	.071	.032	.039	.036	.057	.097	—

Specimen	Form ratio of volutions					Septal count				
	1	2	3	4	5	1	2	3	4	5
1	1.1	1.8	2.4	2.7	—	—	—	—	—	—
2	2.0	2.0	—	—	—	—	—	—	—	—
3	1.1	1.8	2.2	1.9	—	—	—	—	—	—
4	1.2	2.1	2.6	2.9	2.3	—	—	—	—	—
5	—	—	—	—	—	9	14	12	20	—
6	—	—	—	—	—	7	12	15	19	19

Specimen	Tunnel angle (degrees)			
	1	2	3	4
1	26	28	40	—
2	28	28	38	56
3	27	30	41	—
4	18	26	25	37
5	—	—	—	—
6	—	—	—	—

cave lateral slopes, and bluntly pointed to rounded polar ends. Larger specimens of four and a half to six volutions are 1.7 to 2.9 mm. long and 0.6 to 1.0 mm. wide, giving form ratios of 2.6 to 3.0. The holotype of six and a half volutions is 2.9 mm. long and 1.0 mm. wide, giving a form ratio of 2.9. The first volution of many specimens has the axis of coiling at a considerable angle to that of outer volutions, and it is somewhat evolute with a form ratio slightly less than unit value. Beyond the first volution the shell becomes elliptical in cross section in the second volution and assumes its general mature shape in the third to fourth volutions. Averages of the form ratios of the first to the sixth volution of four specimens are 1.3, 1.9, 2.4, 2.5, 2.3, and 2.7, respectively. The form ratios of the first to sixth volution of the holotype are 0.9, 1.5, 2.0, 2.5, 3.0, and 3.0, respectively.

The proloculus is small and spherical in shape, with an outside diamater of 71 to 95 microns. Its walls are thin and without observable structure, except for the proloculus pore. The chambers increase in height about uniformly throughout growth. Averages of the height of the chambers in the first to the sixth volution of six specimens are 27, 49, 67, 83, 98, and 143 microns, respectively. The chambers are lowest immediately above the tunnel, and they increase in height slowly but about uniformly toward the polar ends.

The spirotheca is typical of the genus. The upper tectorium becomes relatively thick along the lateral slopes as the polar region is approached.

The septa are moderately widely spaced. They are plane in the central region of the shell and show only a slight amount of regular fluting in the extreme polar regions of outer volutions in larger specimens. The septal counts of the first to the fifth volution of a typical specimen are 7, 12, 18, 19, and 19, respectively.

The tunnel is narrow in the inner volutions but becomes broad in the outer volutions of larger specimens. Averages of the tunnel angles in the first to the fourth volution of four specimens are 25, 28, 38, and 46 degrees, respectively. The chomata are broad and high in outer volutions but are indistinct in the first one to two volutions. They fill more than half the chambers in the outer volutions and extend laterally to join the heavy upper tectorium along the lateral slopes.

Remarks.—Profusulinella kentuckyensis has a shell that is more highly elongate and subcylindrical in shape than any other species of the genus in America, and it can be distinguished from all other American species of the genus by its shape alone. The highly elongate shape of the shell indicates that this species is an advanced form of the genus.

Occurrence.—Profusulinella kentuckyensis is abundant in the two limestones exposed on the northwest road cut of U. S. Highway 231 immediately north of Green River and about a mile north of Morgantown, Kentucky (Ky-2, Ky-3) where they are associated with large numbers of the ozawainellid fusulinids, illustrated here as *Millerella* spp. and *Paramillerella* sp.

FUSULINELLA IOWENSIS Thompson
Pl. 105, figs. 1–11

Fusulinella iowensis THOMPSON, 1934, p. 296,297, pl. 20, figs. 28–30; THOMPSON, 1936, p. 675, 676, pl. 90, figs. 12–16; DUNBAR & HENBEST, 1942, p. 93–95, pl. 3, figs. 10–25; THOMPSON, 1948, p. 155, pl. 26, fig. 12.

The specimens here illustrated from the type section of the Curlew limestone exposed on Indian Hill, Union County, Kentucky compare closely with the type specimens of this species from the Desmoinesian in Iowa, except that their septa seem somewhat more highly fluted along the lateral slopes and their shells are somewhat larger. The Kentucky specimens are larger and contain a larger number of volutions than the holotype. Their septa are more highly fluted immediately above the tunnel, for closed chamberlets do occur above the tunnel. The Kentucky material may represent a new subspecies due to geographic variation, but we prefer to consider them, for the present at least, as the typical subspecies. The following description is based on the Kentucky collections.

The shell is highly inflated fusiform in shape; with a straight axis of coiling, concave lateral slopes, and extended and narrowly rounded polar ends. Larger shells of nine to eleven volutions are 3.2 to 4.1 mm. long and 2.0 to 2.4 mm. wide, giving form

MEASUREMENTS OF *FUSULINELLA IOWENSIS* THOMPSON, IN MILLIMETERS

Specimen	L.	W.	Ratio	Vol.	Diam. prol.	Height of volutions 1	2	3	4	5	6	7	8	9	10	11
1	3.5	2.2	1.6	9	—	—	.044	.084	.091	.101	.114	.166	.172	.180	—	—
2	3.2	2.0	1.6	8½	—	—	.051	.077	.093	.085	.140	.156	.180	.200	—	—
3	3.4	2.1	1.6	9½	.114	.029	.043	.068	.052	.104	.110	.133	.161	.160	—	—
4	3.4	2.4	1.4	10½	.102	.019	.054	.055	.077	.087	.100	.138	.172	.155	.187	.184
5	4.1	2.2	1.8	9½	.101	.034	.066	.061	.079	.091	.111	.138	.127	.185	.198	—
6	—	2.2	—	8¾	.128	.043	.053	.078	.097	.124	.127	.136	.195	.213	—	—

Specimen	Pro.	Thickness of spirotheca 5	6	7	8	9	10	11	Form ratio of volutions 1	2	3	4	5	6	7	8	9	10
1	—	—	.009	.011	.013	.021	—	—	1.0	1.2	1.3	1.3	1.3	1.3	1.3	1.4	1.6	—
2	—	.007	.008	.009	.010	.010	—	—	1.2	1.2	1.4	1.5	1.4	1.4	1.5	1.5	—	—
3	.020	.009	.007	.009	—	—	—	—	1.4	1.3	1.3	1.5	1.5	1.7	1.9	1.9	1.8	—
4	.018	.005	.009	.006	—	.011	—	.022	1.2	1.3	1.4	1.5	1.2	1.2	1.4	1.4	1.4	1.5
5	.018	.012	.011	.014	.011	.014	.020	—	1.2	1.4	1.4	1.7	1.6	1.7	1.6	1.7	1.8	1.8
6	.019	.008	.004	.009	.008	.014	—	—	—	—	—	—	—	—	—	—	—	—

Specimen	Tunnel angle (degrees) 1	2	3	4	5	6	7	8	9
1	—	—	—	13	12	17	18	—	—
2	—	—	—	9	12	13	16	15	—
3	—	—	—	11	12	14	15	17	—
4	—	—	—	9	10	15	13	13	12
5	—	—	—	9	12	12	13	17	16
6	—	—	—	—	—	—	—	—	—

ratios of 1.4 to 1.8. The first volution is almost spherical in shape but beyond there the shell rapidly becomes elliptical to inflated fusiform. Averages of the form ratios of the first of the tenth volution of five specimens are 1.2, 1.3, 1.4, 1.5, 1.4, 1.5, 1.5, 1.6, 1.6, and 1.7, respectively.

The proloculus is small and spherical in shape. Its outside diameter measures 102 to 128 microns and averages about 110 microns. The shell expands slowly but about uniformly throughout growth. Averages of the heights of the chambers above the tunnel in the first to the eleventh volution of six specimens are 31, 52, 71, 83, 115, 120, 144, 168, 168, 168, and 184 microns, respectively. The chambers are lowest above the tunnel, and they increase in height slowly toward the polar ends.

The spirotheca is composed of the upper tectorium, tectum, diaphanotheca, and lower tectorium. Both tectoria are variable in thickness but do become very massive in parts of the shell. Averages of the thicknesses of the tectum plus the diaphanotheca in the sixth to the eleventh volution of six specimens are 8, 9, 10, 16, 15, and 22 microns, respectively.

The septa are moderately closely spaced throughout the shell. A typical sagittal section has 13, 22, 26, 27, 37, 42, 39, and 50 septa in the first to the eighth volutions.

EXPLANATION OF PLATE 106

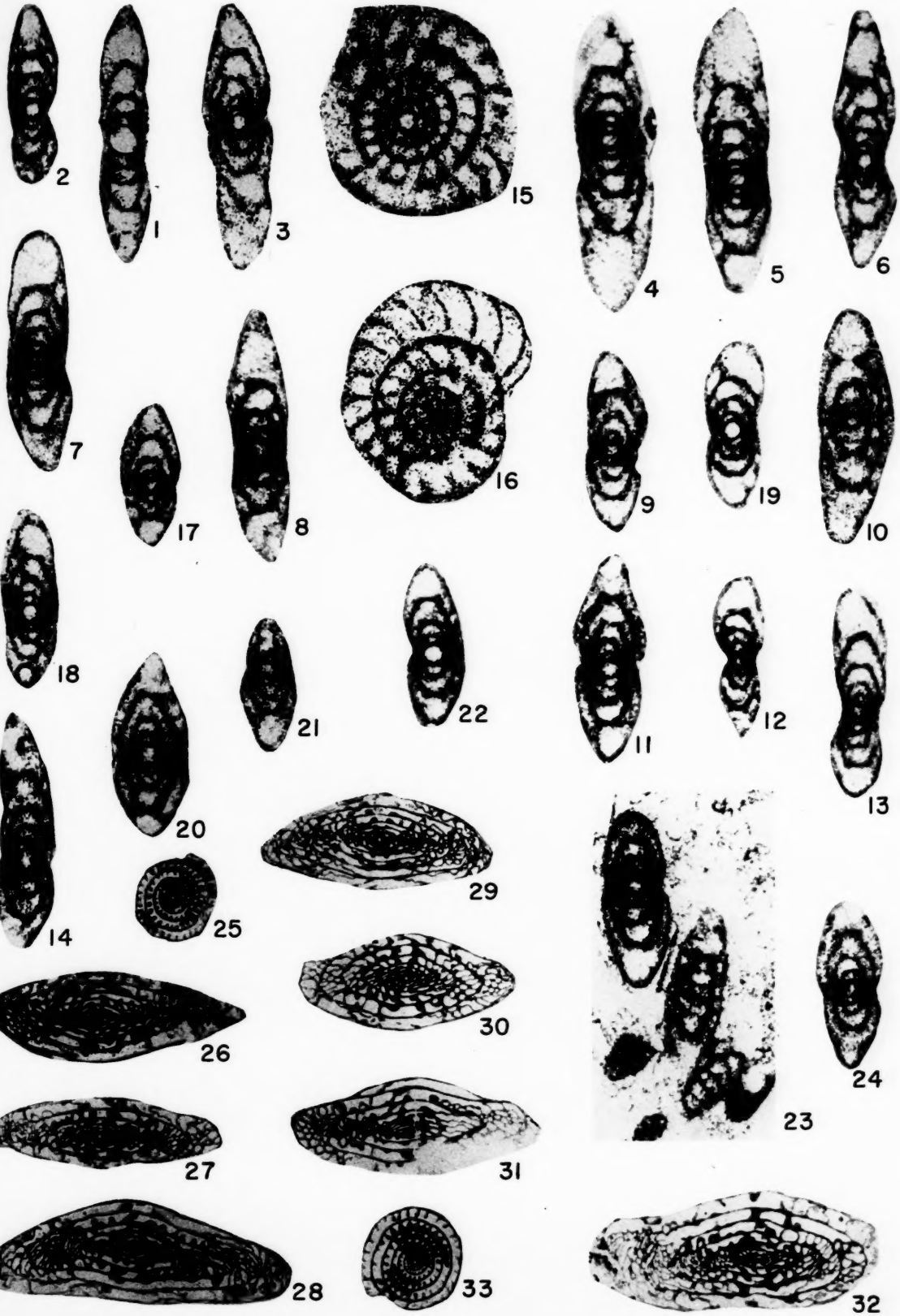
All-illustrations on this plate are unretouched photographs. *1–24* are magnified ×100, and all others are magnified ×10. *1,3,6,8,9,11,12,14–19,21,23,* and *24* are from Collection Ky-2; *2,4,5,7,10,13,20,* and *22* are from Ky-3; *25–27* and *29–32* are from Collection Ill-464; and *28* and *33* are from Ill-235.

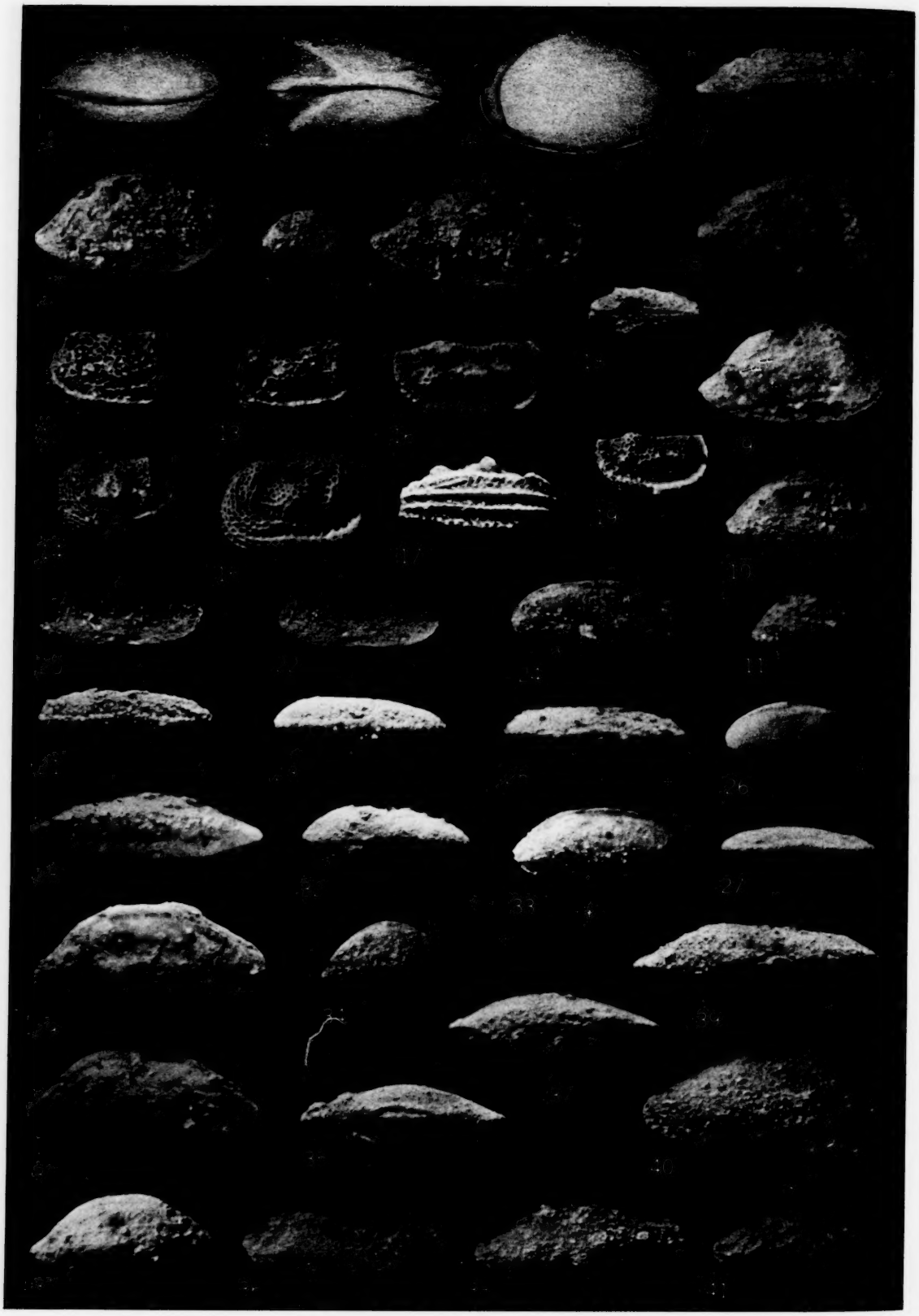
FIGS. *1–16—Millerella* spp. *1*, Axial section with an abnormally large proloculus; *2–14*, axial sections; and *15,16*, sagittal sections.

17–24—Paramillerella sp. Axial sections, with section of rock showing axial and tangential sections in *23*.

25–28—Fusulina aff. *F. leei* Skinner. *25*, Sagittal section; *26,27*, axial sections; *28*, axial section of an unusually long specimen.

29–33—Fusulina serotina (Thompson). *29*, Axial section; *30*, oblique section; *31,32*, tangential section showing nature of septal fluting; and *33*, sagittal section.


2
1
3
15
4
5
6
7
17
8
16
9
19
10
18
21
22
11
12
13
20
29
14
25
23
24
30
26
27
31
28
33
32



The septa are plane in the center of the shell in the first six volutions and are fluted at their lowest margins in the polar regions. However, in outer volutions of larger shells the fluting extends towards the tunnel and closed chamberlets occur at the base of chambers above the tunnel in the eighth to eleventh volutions.

The tunnel is narrow in the first seven volutions, and it increases in width only slowly in outer volutions. Its path is straight to irregular. The tunnel angle remains of near the same volume throughout the shell, being about 12 degrees in the first two volutions and only 14 degrees in the eighth and ninth volutions. The massiveness of the chomata is one of the outstanding features of the shell. They have steep to vertical tunnel sides and low lateral slopes. In the first five to six volutions they extend to the axial zones as thick deposits on the spirotheca and extend along the septa and spirotheca as heavy coatings of somewhat variable thicknesses in outer volutions. The chomata completely fill chambers beside the tunnel in the inner seven volutions except for small tube-like lateral openings at the top and center of the chambers. Thick chomata deposits spread onto the tops of the chambers in all except the ultimate volution.

Remarks.—*Fusulinella iowensis* and its several subspecies are widespread in the United States and characterize a thin unit of rocks near the base of the Desmoinesian as far west at least as New Mexico and Utah and to Ohio on the east. In many regions it occurs above advanced forms of *Fusulinella* and immediately below primitive *Fusulina* and primitive *Wedekindellina*. They are among the last of the *Fusulinella* in America, except for the Desmoinesian *Fusulinella*

EXPLANATION OF PLATE 107

Figures *1,4*, and *5* are camera lucida drawings; all others are unaltered photomicrographs. All specimens are from Morgantown, Kentucky, except as otherwise noted. All figures ×26 except *4* and *5*.

FIGS. *1–3*—*Bairdia dornickhillensis* Harlton. *1,2*, Dorsal and right lateral views of hypotype (InGS 212); *3*, right lateral view of immature specimen (hypotype, InGS 230) of instar 6.

4–5—*Healdia cypha*, n. sp. Dorsal and right lateral views of holotype (InGS 295), ×60.

6—*Bairdia ardmorensis* Harlton. Right lateral view of hypotype (InGS 208).

7–11—*Bairdia antamputata*, n. sp. *7,8*, Dorsal and right lateral views of holotype (InGS 231); *9*, right lateral view of paratype (InGS 232); *10,11*, right lateral views of immature specimens of instar 8 (paratype, InGS 233) and instar 6? (paratype, InGS 235).

12–15—*Amphissites rothi* Bradfield. *12,13*, Right and left valves of hypotypes (InGS 301, 302); *14*, left valve of hypotype (InGS 306) from the Fulda limestone in roadcut on State Highway 545, SW¼ NE¼ SW¼ sec. 11, T. 5 S., R. 4 W., Spencer County, Indiana; *15*, left valve of Bradfield's holotype (I. U. 2119) from the Joliff limestone, Dornick Hills group, about 3 miles east of Ardmore, Oklahoma.

16–19—*Aurikirkbya triseriata*, n. sp. *16,17*, Right lateral and ventral views of holotype (InGS 308); *18,19*, dorsal and right lateral views of an immature specimen (paratype, InGS 310).

20,21—*Fabalicypris minuta* Cooper. Right lateral and ventral views of hypotype (InGS 266).

22,23—*Fabalicypris regularis* Cooper. Right lateral and ventral views of hypotype (InGS 271).

24,25—*Fabalicypris wetumkaensis* Cooper. Right lateral and ventral views of hypotype (InGS 278).

26,27—*Fabalicypris wileyensis* Cooper. Right lateral and ventral views of hypotype (InGS 293).

28–31—*Bairdia isoscelata*, n. sp. *28,29*, Dorsal and right lateral views of holotype (InGS 244); *30*, right lateral view of paratype (InGS 245); *31*, right lateral view of an immature specimen (InGS 248) of instar 8.

32,33—*Bairdia rectifrontis*, n. sp. Dorsal and right lateral views of holotype (InGS 238).

34—*Basslerella* sp. Right lateral view of a complete carapace (InGS 294).

35,36—*Bairdia* cf. *B. legumen* Jones & Kirkby. Dorsal and right lateral views of a nearly complete carapace (InGS 252).

37,38—*Bairdia* sp. Dorsal and right lateral views of a complete carapace (InGS 265).

39–41—*Bairdia opisthorhadina*, n. sp. *39,40*, Dorsal and right lateral views of holotype (InGS 253); *41*, right lateral view of an immature specimen (InGS 261) of instar 7.

like *F. alta* Verville, Thompson, & Lokke recently observed in Desmoinesian rocks of Nevada. Several undescribed and described forms of *Fusulina*, *F.*, n. sp. and *F.*? *insolita* Thompson (Thompson, 1948), have been observed with this group of *Fusulinella*, and it is considered as being within the Zone of *Fusulina* and of Desmoinesian age. It occurs in New Mexico entirely above the top of the Derryan, so far as known at the present time.

This general type of fusulinid occurs in Ohio in the Mercer limestones considerably below the Putnam Hill limestone that contains *Fusulina serotina* (Thompson) and an unnamed species of *Fusulinella*. *F. serotina* is found in Saline County, Illinois, in a limestone above the stratigraphic position of the Curlew limestone of Kentucky.

Occurrence.—*Fusulinella iowensis* described above is common in the type section of the Curlew limestone found on the southwest side of Indian Hill and about 40 feet below the base of the Curlew sandstone that caps the top of Indian Hill (Ky-4). This species and closely related subspecies are abundant in the Boggs limestone, Lower Mercer limestone, and Upper Mercer limestone of Ohio; in the Seville limestone of western Illinois; in an unnamed limestone 20 feet above limestone of Mississippian age in Jefferson County, Iowa; in the Warmington limestone member of the Elephant Butte formation of southern New Mexico; in rocks of equivalent age (lower Sandia formation) in northern New Mexico; and in the lower part of the Hermosa formation and rocks of equivalent age in Colorado.

FUSULINELLA STOUTI Thompson
Pl. 105, figs. 12–24

Fusulinella iowensis var. *stouti* THOMPSON, 1936, p. 676,677, pl. 90, figs. 5–11; DUNBAR & HENBEST, 1942, p. 95, pl. 3, figs. 7,9,8 (?); SMYTH, 1957, p. 263,264, pl. 1, figs. 8,9.

Abundant specimens are present in the limestone exposed on the north side of Kentucky Highway 120, about 5.3 miles west of Providence, Kentucky that resemble the original specimens of *Fusulinella stouti* in most measurable features but are not associated with *F. iowensis* as in most areas where *F. stouti* has been observed. Also, rather common specimens are present in the highly fossiliferous zone, here referred to as the Boskydell? marine zone, in the Delwood sandstone of northern Pope County. They seem almost identical to the Ohio type specimen. A few specimens, like figure 12 on Plate 105, seem abnormally short for this species, but this may be a local variation. The Pope County specimens are not well preserved and we are referring them with question to *F. stouti*.

Fusulinella stouti was originally described from the lower Mercer limestone of Ohio, and it was redescribed from the same limestone by Smyth in 1957. Specimens of it are here illustrated from Pope County, Illinois and Crittenden County, Kentucky. Also, Dunbar & Henbest described and illustrated this form from the Seville limestone in Fulton County, Illinois.

Occurrence.—Specimens of *Fusulinella stouti* here illustrated from Kentucky and southern Illinois were obtained from the Curlew limestone of Crittenden County, Kentucky (Ky-1) and from the marine zone of the Delwood sandstone of northern Pope County, Illinois (Ill-248). Other occurrences are mentioned above.

FUSULINA SEROTINA (Thompson)
Pl. 106, figs. 29–32

Fusulina sp. STOUT, 1918, p. 129,134.
Fusulina secalica CONREY, 1921, p. 115.
Fusulinella serotina THOMPSON, 1936, p. 477,478, pl. 90, figs. 1–4, pl. 91, fig. 9.
Fusulina leei DUNBAR & HENBEST (part), 1942, p. 109–111, pl. 6, fig. 9; SMYTH (part), 1957, p. 266,267, pl. 2, figs. 17–19.

As the above synonymy indicates, *Fusulina serotina* has been the subject of dispute on several occasions. Direct comparison with part of the original collection of *Fusulina leei* from Oklahoma suggests to us that the Illinois specimens are considerably different from those of Oklahoma. They are more highly inflated, are more loosely coiled, have less prominent chomata, and have less intensely fluted septa.

Occurrence.—Abundant specimens of *Fusulina serotina* are found in the limestone formerly referred to the Curlew limestone at several places in Saline County. Also, the form here referred to as *Fusulina* aff. *F. leei* is abundant in the same limestone but the two forms are not always found in direct

association. The specimens here illustrated are from southern Saline County (Ill-464).

FUSULINA aff. F. LEEI Skinner
Pl. 106, figs. 25–28,33

Abundant specimens were obtained from the limestone formerly called Curlew limestone in southern Saline County, Illinois, that resemble *Fusulina leei* Skinner in several respects but which we refer to as *Fusulina* aff. *F. leei* Skinner. A comparison of topotype specimens of *F. leei* from Oklahoma suggests that the Illinois specimens are more slender than those from Oklahoma, have somewhat more massive chomata, and probably have a different degree of septal fluting. It is recognized that they are closely related in age.

Occurrence.—The specimens here illustrated were obtained from Saline County of southern Illinois (Ill-235, Ill-464).

REFERENCES

CONREY, G. W., 1921, Geology of Wayne County: Ohio Geol. Survey, 4th ser., Bull. 24, p. 1–155, pls. 1–10.

COOPER, C. L., 1946, Pennsylvanian ostracodes of Illinois: Illinois Geol. Survey, Bull. 70, 177 p., pls. 1–21.

DUNBAR, C. O., & HENBEST, L. G., 1942, Pennsylvanian Fusulinidae of Illinois: Illinois Geol. Survey, Bull. 67, 218 p., pls. 1–23.

HENBEST, L. G., 1928, Fusulinellas from the Stonefort limestone member of the Tradewater formation: Jour. Paleontology, v. 2, p. 70–85, pls. 8–10.

MÖLLER, V. VON, 1877, Ueber Fusulinen und ähnliche Foraminiferen-Formen des russischen Kohlenkalks: Neues Jb. Min., Geol. und Pal., Jg. 1877, p. 139–146, 1 fig.

SEARIGHT, W. V., & PALMER, E. J., 1957, Burgner Formation, Pre-Desmoinesian Pennsylvanian deposit in southwestern Missouri: Am. Assoc. Petroleum Geologists, Bull., v. 41, p. 2127–2131.

SKINNER, J. W., 1931, Primitive fusulinids of the Mid-Continent region: Jour. Paleontology, v. 5, p. 253–259, pl. 30.

SMYTH, P., 1957, Fusulinids from the Pennsylvanian rocks of Ohio: Ohio Jour. Sci., v. 57, p. 257–283, pls. 1–3.

ST. JEAN, J., JR., 1957, A Middle Pennsylvanian foraminiferal fauna from Dubois County, Indiana: Indiana Geol. Survey, Bull. 10, 66 p., pls. 1–5.

STOUT, WILBUR, 1918, Geology of Muskingum County: Ohio Geol. Survey, 4th ser., Bull. 21, p. 1–351.

THOMPSON, M. L., 1934, The fusulinids of the Des Moines series of Iowa: Iowa Univ. Studies Nat. Hist., v. 16, p. 277–322, pls. 1–4.

——, 1936, Pennsylvanian fusulinids from Ohio: Jour. Paleontology, v. 10, p. 673–683, pls. 90, 91.

——, 1948, Studies of American fusulinids: Univ. Kansas, Paleont. Contrib., Protozoa, Art. 1, 184 p., pls. 1–38.

——, 1951, New genera of fusulinid Foraminifera: Contr. Cushman Found. Foram. Res., v. 2, p. 115–119, pls. 13–14.

——, 1953, Primitive *Fusulinella* from southern Missouri: Jour. Paleontology, v. 27, p. 321–327, pls. 41,42.

VERVILLE, G. J., THOMPSON, M. L., & LOKKE, D. H., 1956, Pennsylvanian fusulinids of eastern Nevada: Jour. Paleontology, v. 30, p. 1277–1287, pls. 133–136.

PART II. PENNSYLVANIAN OSTRACODS FROM MORGANTOWN, KENTUCKY

R. H. SHAVER

THE ostracods are from a one-foot interval of shale at the top of bed 3 and all of bed 5 in the section described under Collection Localities from Morgantown, Kentucky. Samples from other beds in this section are barren or do not contain useable specimens. These are the first Pennsylvanian ostracods to be described from the Kentucky portion of the Illinois Basin.

The fauna consists of 16 species which are mostly Bairdiidae, with Kirkbyidae next in importance (Table 1). Compared to mid-continent faunas, it is most closely similar to that of the lower Dornick Hills group in the Ardmore Basin of Oklahoma. It differs from the Dornick Hills fauna by the presence of *Fabalicypris*.

In the Illinois Basin, the fauna is similar to that of the lowest marine zones in Indiana which are in the Mansfield formation. The Fulda limestone of Indiana was assigned a Morrow age by Cooper (1946), whereas the Ferdinand limestone was assigned an Atoka age. The Morgantown fauna is more like that of the Ferdinand limestone.

Although an appreciable number of species are also known from the Upper Mercer limestone, upper Pottsville series,

TABLE 1—STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION OF THE OSTRACODS

	Eurasia	Midcontinent					Illinois Basin						Ohio		
		Morrow					Mansfield		Tradewater				Pottsville		
	L. Carboniferous	Johns Valley	Wapanucka	L. Dornick Hills	Atoka	Des Moines	Fulda	Ferdinand	Seville	Seahorne	Wiley	Carbondale and McLeansboro	Poverty Run	L. Mercer	U. Mercer
Bairdia antamputata				XX				XX							
B. ardmorensis		X		XX	XX	X		XX					X	X	
B. dornickhillensis				XX	XX	X								X	
B. isoscelata	X														
B. cf. *B. legumen*														X	
B. ophisthorhadina															
B. rectifrontis							X								
B. sp.									X	X				X	
Fabalicypris minuta								X	X						
F. regularis						X		XX	X	X		X		X	X
F. wetumkaensis								XX	X	X	X	X			
F. wileyensis															
Basslerella sp.				X											
Healdia cypha		X		XX			X	X	X				X		
Amphissites rothi			X	XX			XX								
Aurikirkbya triseriata															
	1	2	1	6	2	2	3	6	4	2	1	2	2	4	1
	1	6			2	2	8		4			2	5		

Ohio, they do not include restricted species nor the diagnostic Kirkbyidae.

SYSTEMATIC DESCRIPTIONS

Class OSTRACODA Latreille
Order PODOCOPA Sars
Superfamily CYPRIDACAE Baird
Family BAIRDIIDAE Sars
Genus BAIRDIA McCoy, 1844

BAIRDIA ANTAMPUTATA Shaver, n. sp.

Pl. 107, figs. 7–11

Bairdia cf. *B. ardmorensis* BRADFIELD, 1935, p. 92, pl. 7, figs. 7a,b, lower Dornick Hills group, Oklahoma.

Bairdia pennata COOPER, 1946, p. 49, pl. 4, figs. 3,4, Ferdinand limestone (not Liverpool limestone), Indiana.

Description.—In lateral view: carapace moderately elongate, subrhomboidal; dorsal border angularly arched with straight anterodorsal border meeting posterodorsal border at an angle, and with posterodorsal border angulated outward at a point slightly posterior to its midpoint; ventral border straight to gently convex in central portion; anterior border very narrowly rounded, anteroventrally truncate, with its extremity above midheight; posterior beak acuminate, well below midheight. In dorsal view, carapace thick, with parallel sides and abrupt slopes toward the ends.

Hinge located along the upper segment of the posterodorsal border and with strong posterior inclination; apparent overlap slight around most of the border.

Dimensions.—Holotype: length, 1.25 mm.; height, 0.66 mm.; width, 0.53 mm. Averages for four other specimens (Table 2).

Remarks.—This species differs from *B. pennata* Coryell & Sample, and Cooper (Liverpool limestone) by its greater size and dorsal angularity, with outward postero-

TABLE 2.—DIMENSIONS OF *BAIRDIA ANTAMPUTATA*

Instar	No. specs.	Length, mm.	Height, mm.	Width, mm.
9	1	1.20	0.63	0.56
8	2	0.98	0.53	0.45
6?	1	0.69	0.40	0.33

dorsal angulation (not a concavity), and by its parallel sides in dorsal view. The immature molts differ decidedly from those of *B. dornickhillensis* and show that the species is not a narrow form of *B. oklahomanesis* s. l., i.e., *B. dornickhillensis*, as described by authors. The immature molts are very similar to Bradfield's *B.* cf. *B. ardmorensis*, listed in the synonymy, which I suggest may consist of immature molts of an adult, apparently not figured by Bradfield; however, further investigation may show that Bradfield's specimens and my immature molt (Pl. 107, fig. 10) are adults of a new species.

The specific name is derived from Latin *ante-* ("before, in front") and *amputo* ("to cut off") and refers to the anterior truncation in lateral view.

Types.—Holotype, a complete carapace, InGS 231; paratypes: two carapaces, one complete, InGS 232, 233; four immature molts, InGS 234–237.

BAIRDIA ARDMORENSIS Harlton
Pl. 107, fig. 6

Bairdia ardmorensis HARLTON, 1929, p. 267, pl. 2, fig. 11, Dornick Hills group, Oklahoma; HARLTON, 1933, p. 25, pl. 7, fig. 8, Johns Valley shale, Oklahoma; BRADFIELD, 1935, p. 92, Dornick Hills group, Oklahoma; COOPER, 1946, p. 41, pl. 1, figs. 14,15, Ferdinand limestone, Indiana.

Dimensions.—Averages for four adults from which three measurements were made for each dimension: length, 1.33 mm.; height, 0.67 mm.; width, 0.44. mm.

Remarks.—The acuminate posterior beak, high anterior termination, and anteroventral truncation agree more closely with the type specimen than with the related species *B. harltoni* Cooper which differs in its broader terminations.

Types.—Hypotypes, four carapaces, one broken, InGS 208–211.

BAIRDIA DORNICKHILLENSIS Harlton
Pl. 107, figs. 1–3

Bairdia dornickhillensis HARLTON, 1929, p. 268, pl. 2, figs. 12a,b, Dornick Hills group, Oklahoma; BRADFIELD, 1935, p. 78, pl. 5, figs. 3a,b, Dornick Hills and Deese groups, Oklahoma.
Bairdia oklahomaensis MARPLE, 1952, p. 930, pl. 133, figs. 6–11, Poverty Run member and Lower Mercer limestone, Ohio.

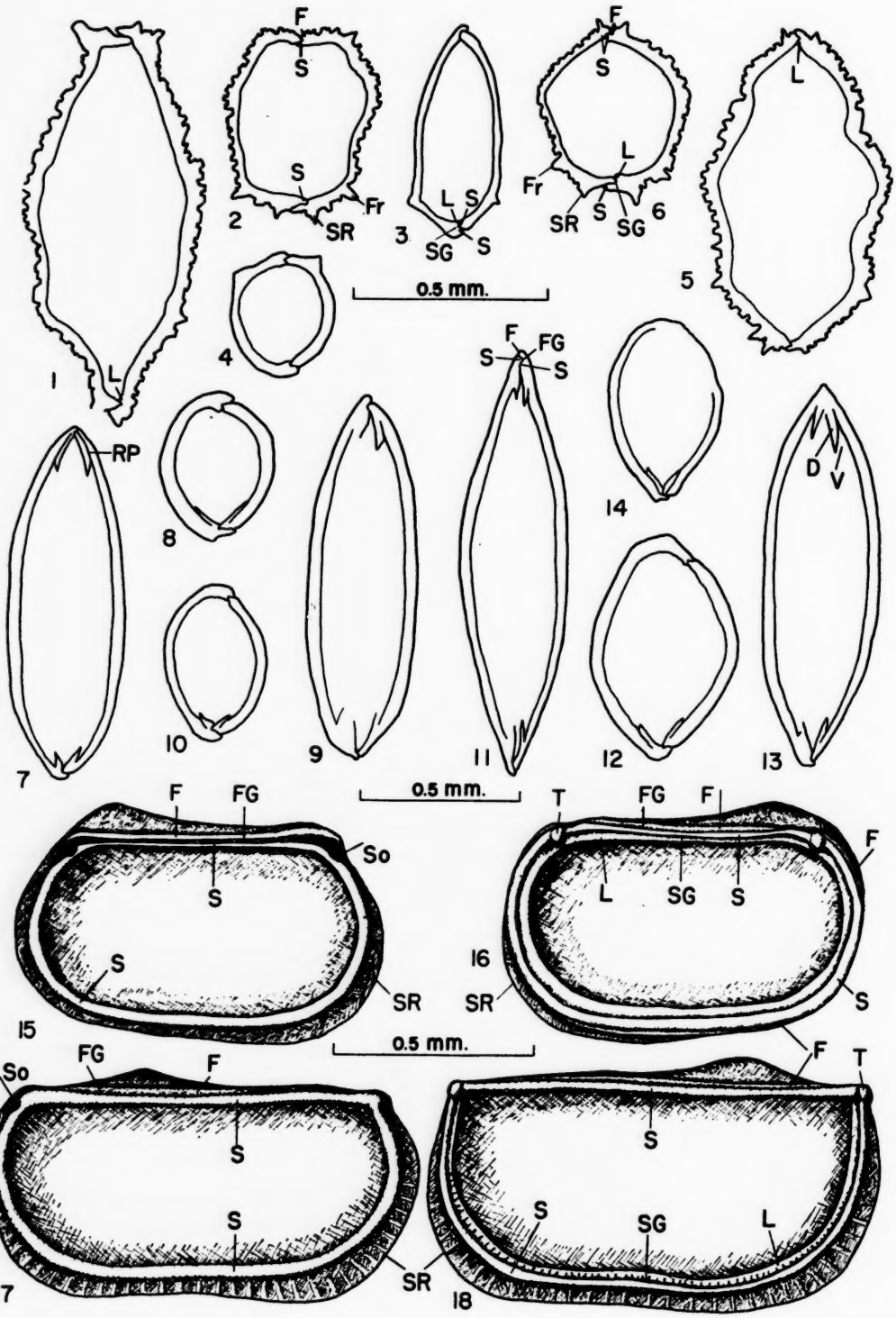
Dimensions.—Averages for 19 specimens (Table 3).

TABLE 3.—DIMENSIONS OF *BAIRDIA DORNICKHILLENSIS*

Instar	Length		Height		Width	
	no. specs.	mm.	no. specs.	mm.	no. specs.	mm.
9	6	1.16	6	0.67	5	0.56
8	5	0.90	5	0.52	4	0.41
7	4	0.72	4	0.42	3	0.35
6	3	0.54	3	0.32	3	0.26

The average growth factor for length between instars is 1.29.

Remarks.—The species is listed in synonymies of *B. oklahomaensis* Harlton (=*B. auricula* Knight). Cordell (1952) disagreed that *B. oklahomaensis* has such latitude. I consider that the lower-extending range of the type of ostracod here referred to *B. dornickhillensis* justifies separate recognition. Authors emphasize the prominent swelling along the posterodorsal slope, with interruption of overlap, of *B. oklahomaensis*. Harlton's original description of *B. dornickhillensis* includes "dorso-posterior slope with small curve near middle," and his figures agree, without conspicuous angulation and interruption of overlap. Bradfield (1935) separated *B. oklahomaensis* and *B. auricula* on the basis of posterior and anterior positions, respectively, of the highest point on the line of commissure. With similar ranges, the distinction may not be valid; however, the highest point on specimens of middle and late Pennsylvanian age is quite generally at a second point of conspicuous angulation which is lacking from early Pennsylvanian specimens here referred to *B. dornickhillensis*. The two types undoubtedly are related, with the characteristic dorsal angularity of *B. oklahomaensis*


F
S
S
Fr
SR
2
L
S
SG
S
3
F
S
L
Fr
SR
S
SG
6
L
5
4
0.5 mm.
1
L
F
FG
S
S
RP
8
14
D
V
7
10
9
11
12
13
0.5 mm.
F
FG
So
S
S
SR
15
T
FG
F
F
L
SG
S
16
SR
S
0.5 mm.
So
FG
F
F
T
S
S
S
S
SG
L
SR
17
18

developing out of the earlier smoother forms. *B. oklahomaensis* of McLaughlin (1952), Payne (1937, pl. 39, figs. 9a,b), and Johnson (1936) are rare examples of higher occurrences of the rounded type; it is doubted that these also have the extremely long, parallel sides of *B. dornickhillensis* in dorsal view.

Types.—Hypotypes; six carapaces, InGS 212–217; 13 immature molts, InGS 218–230.

BAIRDIA ISOSCELATA Shaver, n. sp.
Pl. 107, figs. 28–31; text-fig. 2: 11,12

Description.—In lateral view: carapace elongate, subtrapezoidal; central dorsal and ventral borders nearly straight, parallel; anterodorsal and posterodorsal borders abrupt, nearly straight, making conspicuous cardinal angles of about 155 and 145 degrees with hinge line; ventral border merges through short, gentle, symmetrical upsweeps into low, narrowly rounded anterior border and low, acuminate, slightly upturned posterior beak. In dorsal view, carapace attenuate, with symmetrically convex lateral outlines.

Hinge line long and horizontal; left valve larger, overlapping the right except terminally; overlap along anterior border reversed to right over left in some specimens through development of the flange in right valve; ridge and groove hingement and contact-marginal structures, with duplicature and vestibule, are developed as in most Bairdiidae.

Dimensions.—Holotype: length, 1.50 mm.; height, 0.66 mm.; width, 0.46 mm. Averages for nine specimens, some incomplete (Table 4).

TABLE 4.—DIMENSIONS OF *BAIRDIA ISOSCELATA*

Instar	Length		Height		Width	
	no. specs.	mm.	no specs.	mm.	no. specs.	mm.
9	4	1.47	7	0.66	5	0.46
8	1	1.15	1	0.49	1	0.36

Remarks.—Large, elongate bairdiids of this type which have the classic bairdian outline as opposed to the modifications shown by *Fabalicypris*, commonly are called *Bairdia plebeia* Reuss, *B. reussiana* Kirkby, *B. schaurothiana* Kirkby, and *B. hisingeri* (Münster). The apparently infinite variations and gradations among these species are not uniformly interpreted, so that reported ranges are uncommonly long, in Eurasia, from the Calciferous sandstone (Lower Carboniferous) through Permian, and in America, Pennsylvanian and Permian.

The nine specimens of *Bairdia isoscelata* show constancy in the angular dorsal border, strong apparent overlap, low position of the anterior and posterior terminations, narrowly rounded (not truncate) anterior border and acuminate posterior beak, which characters include those emphasized by Kellett (1934) as of specific value in *Bairdia*. These characters jointly or singly differentiate the new species from the type figures of the European species named. Few bairdiids compare closely with *Bairdia isoscelata* in its narrow sense (Table 5). With decreasing age, those which I have selected

TEXT-FIG. 2—Morphology of the ostracods. *1,2,17,18, Aurikirkbya triseriata*, n. sp.: *1,2*, longitudinal and transverse sections; *17,18*, interiors of left and right valves. *3,4, Healdia cypha*, n. sp., longitudinal and transverse sections. *5,6,15,16, Amphissites rothi* Bradfield; *5,6*, longitudinal and transverse (immature) sections; *15,16*, interiors of left and right valves. *7,8, Fabalicypris wetumkaensis* Cooper, longitudinal and transverse sections. *9,10, Bairdia rectifrontis*, n. sp., longitudinal and transverse sections. *11,12, Bairdia isoscelata*, n. sp., longitudinal and transverse sections. *13,14, Bairdia opisthorhadina*, n. sp., longitudinal and transverse sections. All longitudinal sections include the greatest length and are shown with the anteriors at top as seen in dorsal view; all transverse sections are near the center of the hinge and are shown with hinges at top as seen from the posterior. D—duplicature, F—flange, FG—flange groove, Fr—frill, L—list, RP—radial porecanal, S—selvage, SG—selvage groove, So—socket, SR—submarginal ridge, T—tooth, V—vestibule.

TABLE 5—CHARACTERS OF CERTAIN BAIRDIIDS

Species and age	No. specs.	L	H	W	L/H	Anterior border	Posterior beak
		mm.	*mm.*	*mm.*	*mm.*		
B. reussiana, Kellett, L. Perm.	3	1.33	.60	.38	2.2	high, truncate	high, blunt
B. reussiana, Cordell, U. Penn	1	1.40	.60	.39	2.3	high, truncate	med. height, broad
B. schaurothiana, Marple, L. Penn.	1	1.18	.51		2.3	low, rounded	low, acuminate
B. schaurothiana, Cooper, L. Penn.	1	1.55	.73	.58	2.1	med. height, rounded	med. height, broad
B. isoscelata, L. Penn.	8	,1.47	.66	.46	2.2	low, rounded	low, acuminate
B. hisingeri mongoliensis J. & K., L. Carb.	1	1.88	.76		2.5	low, rounded	low, acuminate
B. hisingeri, J. & K., L. Carb.	1	2.14	.76		2.8	low, rounded	low, acuminate

for comparison generally show decrease in size and elongation, increase in heights of the anterior and posterior terminations, truncation of the anterior border, and broadening of the posterior beak. The posterior beaks of Kellett's Permian specimens of *B. reussiana* have borders which meet at obtuse angles; the molts have high beaks, contrasting with the young of the new species. (Compare pl. 107, fig. 29, with Kellett, 1934, pl. 17, figs. 1a–h,4a,b). Table 5 suggests that the single specimen of Marple is immature.

The specific name is derived from Greek *ἰσο-* ("equal") and *σκέλος* ("leg") and refers to the isosceles-trapezoidal shape in lateral view.

Types.—Holotype, a complete carapace, InGS 244; paratypes: three complete carapaces, InGS 245–247; an immature carapace, InGS 248; one longitudinal and two transverse sections, InGS 249–251.

BAIRDIA cf. B. LEGUMEN Jones & Kirkby
Pl. 107, figs. 35,36

Bairdia legumen JONES & KIRKBY, 1885, p. 266, pl. 9, figs. 13a,b, Yoredale series, Carboniferous, Great Britain.

Dimensions.—A nearly complete carapace, InGS 252: estimated length 1.36 mm.; height, 0.56 mm.; width, 0.46 mm.

Remarks.—The species is characterized by its truncate anterior border with high termination, low posterior beak, line of greatest height well toward the anterior end, relatively short anterodorsal slope, and by the greatest width anterior to middle at point of greatest convexity from which the lateral outlines extend in nearly straight lines toward the ends. The specimen from Morgantown differs from the type figure of *B. legumen* by having a slightly less acute anterior border and longer anterodorsal slope.

BAIRDIA OPISTHORHADINA Shaver, n. sp.
Pl. 107, figs. 39–41; text-fig. 2: 13,14

Bairdiacypris trojana MARPLE, 1952, p. 931, pl. 133, fig. 15, Lower Mercer limestone, Ohio.

Description.—In lateral view: carapace elongate, tapering posteriorly; dorsal border gently arched, with anterior three-fifths in a broad curve rounding imperceptibly into anterior border; posteriorly, the curve breaks at a point two-fifths of the length from the posterior termination, from which point the long posterodorsal slope is straight, becoming concave terminally; ventral border nearly straight, with long, gentle posteroventral upsweep; terminal extremities below midheight, the anterior border broadly rounded, the posterior border narrowly rounded. In dorsal view, sides subparallel.

Contact-marginal structures, with duplicature and vestibule, developed as in other Bairdiidae; apparent overlap slight, greatest central dorsally and ventrally.

Dimensions.—Holotype: length, 1.52 mm.; height, 0.65 mm.; width, 0.46 mm. Averages for nine paratypes (Table 6).

Remarks.—This species is characterized by its long, narrow, tapering posterior; it differs from *Bairdia hoxbarensis* Harlton and *B. trojana* Wilson by having a much longer and less abrupt posterodorsal slope, and

TABLE 6—DIMENSIONS OF *BAIRDIA OPISTHORHADINA*

Instar	Length		Height		Width	
	no. specs.	mm.	no. specs.	mm.	no. specs.	mm.
9			1	0.69	1	0.46
8	1	1.34	2	0.63	2	0.40
7	3	1.09	3	0.49	2	0.35
6	1	0.82	1	0.36	1	0.26
5?	2	0.68	2	0.32	2	0.23
4?	1	0.60	1	0.28		

from *B. glennensis* Harlton by its resupinate dorsal border and by having more of the prosaic bairdian outline. The specimens of Marple which are listed in the synonymy are intermediate between *B. trojana* and the new species and could be referred to either species.

The specific name is derived from Greek *ὀπισθο-* ("behind, backward") and *ῥαδινός* ("tapering") and refers to the posterior tapering of the outline in lateral view.

Types.—Holotype, a complete carapace, InGS 253; paratypes: one carapace, nearly complete, InGS 254; eight immature molts, InGS 255–262; one transverse and one longitudinal section, InGS 263, 264.

BAIRDIA RECTIFRONTIS Shaver, n. sp.
Pl. 107, figs. 32,33; text-fig. 2: 9, 10

Description.—In lateral view: carapace elongate, subrhomboidal; dorsal border in a long low arch, with very short transition into anterior border; anterior border truncate, with termination well above midheight, meeting dorsal border nearly at a right angle, especially in right valve; posterodorsal slope prominent with long extent into low, moderately acuminate posterior beak; central ventral border nearly straight. In dorsal view: carapace thick, with broadly convex sides converging anteriorly; greatest width posterior.

The ridge and groove hingement and contact-marginal structures with duplicature and vestibule are developed as in most Bairdiidae; overlap is left over right, decreasing toward the anterior and posterior borders.

Dimensions.—Holotype: length, 1.05 mm.; height, 0.48 mm.; width, 0.39 mm. Averages for five other carapaces: length, 1.09 mm.; height, 0.47 mm.; width, 0.39 mm.

Remarks.—This species resembles *Bairdia hoxbarensis* Harlton (Cordell, 1952, p. 86, synonymy) which is of Des Moines and later age; *B. rectifrontis* differs by having a subrhomboidal outline in lateral view, truncated anterior border, and generally lower posterior and higher anterior terminations. It differs from species of *Pseudobythocypris* Shaver (1958) and other Healdiidae by having a duplicature and vestibule.

The specific name is derived from Latin *rectus* ("straight") and *frons* ("forehead, brow") and refers to the truncated anterior border.

Types.—Holotype, a complete carapace, InGS 238. Paratypes: two complete carapaces, InGS 239, 240; one longitudinal and two transverse sections, InGS 241–243.

BAIRDIA sp.
Pl. 107, figs. 37,38

Bairdia cf. *B. glennensis* COOPER, 1946, p. 45, pl. 2, fig. 7, Fulda limestone, Indiana.

Description.—Carapace very elongate, nearly as wide as high. In lateral view: rhomboidal, with low dorsal arch broken in the posterior half by an angle from which the dorsal border is very gently inclined anteriorly, the posterodorsal border more steeply inclined; ventral border nearly straight; anterior border narrowly rounded above, obliquely truncate below, with high termination; posterior beak long, narrow, with slightly concave posterodorsal slope and low termination. In dorsal view, lateral outlines evenly convex with unbroken lines.

Apparent overlap is narrow and uniform except where it is absent terminally.

Dimensions.—A complete carapace, InGS 265: length, 1.34 mm.; height, 0.48 mm.; width, 0.42 mm.

Remarks.—This rare species differs from *B. glennensis* Harlton by its more angular dorsal border, truncate anterior border, and by having more of the bairdian outline; it is much more elongate than *B. legumen* Jones and Kirkby.

Genus FABALICYPRIS Cooper, 1946

Specimens of *Fabalicypris* are very common in the Morgantown sample. At least

three distinct types are recognized which apparently gain some support as separate entities from the immature molts. A small elongate form is referred to *F. regularis*; a small form with high dorsal arch and low degree of symmetry in lateral view is assigned to *F. minuta*; a larger and more robust form with greater apparent overlap to *F. wetumkaensis*; a fourth type called *F. wileyensis* has almost perfect symmetry in lateral view but is represented by only one specimen.

FABALICYPRIS MINUTA Cooper
Pl. 107, figs. 20,21

Fabalicypris minuta COOPER, 1946, p. 60, pl. 5, figs. 31,32, Seville and Seahorne limestones, Illinois; MARPLE, 1952, p. 931, pl. 133, figs. 18,19, Lower Mercer limestone, Ohio.

Dimensions.—Averages for two complete carapaces: length, 1.05 mm.; height, 0.45 mm.; width, 0.35 mm. Averages for two specimens of instar 8: length, 0.87 mm.; height, 0.39 mm.; width, 0.29 mm. One specimen of instar 6?: length, 0.61 mm.

Remarks.—*F. minuta* is characterized by its high dorsal arch and low anterior and posterior terminations. Marple suggested that specimens of *F. minuta* may be immature molts of *F. wetumkaensis* which remains a possibility, but in my sample, the size relationships do not fit well in the molt series of *F. wetumkaensis*.

Types.—Hypotypes: two complete carapaces, InGS 266, 267; three immature molts, InGS 268–270.

FABALICYRPIS REGULARIS Cooper
Pl. 107, figs. 22,23

Fabalicypris regularis COOPER, 1946, p. 60, pl. 6, figs. 1–3, Ferdinand and Seville limestones, Indiana and Illinois.

Dimensions.—Averages for eight specimens (Table 7):

TABLE 7—DIMENSIONS OF *FABALICYPRIS REGULARIS*

Instar	Length		Height		Width	
	no. specs.	mm.	no. specs.	mm.	no. specs.	mm.
9	5	1.08	5	0.40	4	0.36
8	2	0.89	2	0.33	1	0.30
7	1	0.71				

Remarks.—Specimens of *F. regularis* compare closely with the holotype by having a slight posterodorsal angulation, concave ventral border, slightly acuminate posterior, and uniform overlap with gentle ventral offset; they are slightly more elongate than the holotype, and some show slight anteroventral truncation, which characters resemble those of *F. warthini* (Bradfield).

Types.—Hypotypes: five carapaces, one corroded, InGS 271–275; three immature molts, InGS 276–277.

FABALICYPRIS WETUMKAENSIS Cooper
Pl. 107, figs. 24,25; text-fig. 2: 7,8

Fabalicypris wetumkaensis COOPER, 1946, p. 61, pl. 6, figs. 12–19, Ferdinand to Collinsville limestones, Indiana and Illinois; MARPLE, 1952, p. 932, pl. 133, figs. 20,21, Poverty Run member and Lower and Upper Mercer limestones, Ohio.

Bairdia haworthi WARTHIN, 1930, p. 72, pl. 6, figs. 4a,b, upper Des Moines series, Oklahoma.

Dimensions.—Averages for 13 specimens (Table 8):

TABLE 8—DIMENSIONS OF *FABALICYPRIS WETUMKAENSIS*

Instar	Length		Height		Width	
	no. specs.	mm.	no. specs.	mm.	no. specs.	mm.
9	5	1.16	2	0.49	1	0.34
8	6	0.88	4	0.40	4	0.30
7	2	0.68	2	0.32	1	0.24

Remarks.—*F. wetumkaensis* is distinguished by its slightly concave ventral border and is intermediate between the almost perfectly symmetrical type species, *F. wileyensis*, and species which are near *Bairdia* in outline in lateral view. *F. wetumkaensis* has structures of the contact margin which are similar to those of species of *Bairdia* and distinguish the genus from *Waylandella* Coryell & Billings and *Pseudobythocypris* Shaver of the family Healdiidae.

Types.—Hypotypes: five carapaces, three deformed, InGS 278–282; eight immature molts, InGS 283–290; one transverse and one longitudinal section. InGS 291, 292.

FABALICYPRIS WILEYENSIS Cooper
Pl. 107, figs. 26,27

Fabalicypris wileyensis COOPER, 1946, p. 61, pl. 6, figs. 4–8, Ferdinand limestone, Indiana, to

Summum cyclothem, Illinois; MARPLE, 1952, p. 932, pl. 134, figs. 1–3, Lower and Upper Mercer limestones, Ohio.

Dimensions.—Hypotype, InGS 293: length, 0.96 mm.; height, 0.45 mm.; width, 0.32 mm.

Remarks.—The single specimen may be an immature molt, but its symmetrical outline in lateral view distinguishes it from all other specimens in the sample.

Superfamily CYTHERACEA Baird
Family CYTHERIDAE Baird
Genus BASSLERELLA Kellett, 1935
BASSLERELLA sp.
Pl. 107, fig. 34

Dimensions.—A complete carapace, InGS 294: length, 0.75 mm.; height, 0.46 mm.; width, 0.33 mm.

Remarks.—None of the internal structures can be observed in the single specimen which differs from described species by having a sharply concave posteroventral border.

Order PLATYCOPA Sars
Family HEALDIIDAE Harlton
Genus HEALDIA Roundy, 1926
HEALDIA CYPHA Shaver, n. sp.
Pl. 107, figs. 4,5; text-fig. 2: 3,4

Healdia sp. BRADFIELD, 1935, p. 106, pl. 9, figs. 6–8, Joliff and Otterville limestones, Oklahoma.

Description.—In lateral view: carapace short, subtriangular; dorsal border with high angled arch, with highest point near midlength; anterodorsal slope steeply inclined, straight or gently curved, and rounding into anterior border; posterodorsal border steep and straight; anterior and posterior borders in varying degrees of narrow rounding; ventral border convex. In dorsal view: carapace wide, wedge-shaped, with abrupt posterolateral slopes from the shoulders; greatest width at shoulders.

Shoulders project slightly into weak ridge; spines very weak or absent. Apparent overlap is moderate, left over right, and decreases along the posterodorsal slope. Hinge, located posterodorsally, and contact margin of left valve are interpreted as consisting principally of selvage, and proximally from it, selvage groove and list; hinge and contact margin of right valve consist principally of the selvage; separated calcified inner lamella and vestibule lacking.

Dimensions.—Holotype: length, 0.53 mm.; height, 0.35 mm.; width, 0.27 mm. Averages for five paratypes (Table 9):

TABLE 9—DIMENSIONS OF *HEALDIA CYPHA*

Instar	Length		Height		Width	
	no. specs.	mm.	no. specs.	mm.	no. specs	mm.
9	4	0.54	4	0.35	2	0.28
8	1	0.46	1	0.29	1	0.25

Remarks.—The high dorsal angle, narrowly rounded terminal borders, and slightly ridged shoulders distinguish *Healdia cypha* from most other healdiids. The Morgantown specimens are nearer those figured by Bradfield from the Joliff limestone than those from the Otterville but nevertheless have somewhat broader posteriors in lateral view. The species differs from *H. boggyensis* Harlton and *H. boggyensis* Cooper (1946) by having a higher dorsal angle. This difference may not be significant in the case of Cooper's specimens inasmuch as wide variations are common in species of *Healdia*.

The specific name is derived from Greek κῦφος ("bent, humpbacked") and refers to the high-angled dorsum.

Types.—Holotype, a complete carapace, InGS 295. Paratypes: a complete carapace, InGS 296; a left valve, InGS 297; an immature molt, InGS 298; one transverse and one longitudinal section, InGS 299, 300.

Order PALEOCOPA Henningsmoen
Superfamily BEYRICHIACEA Ulrich
Family KIRBYIDAE Ulrich & Bassler
Genus AMPHISSITES Girty, 1910
AMPHISSITES ROTHI Bradfield
Pl. 107, figs. 12–15; text-fig. 2: 5,6,15,16

Amphissites rothi BRADFIELD, 1935, p. 57, pl. 4, fig. 1, lower Dornick Hills group, Oklahoma.
Amphissites sp. HARLTON, 1933, p. 23, pl. 6, fig. 6, Johns Valley shale, Oklahoma.
Ectodemites harltoni COOPER, 1946, p. 102, pl. 15, fig. 44, Fulda and Seville limestones, Indiana and Illinois; MARPLE, 1952, p. 935, pl. 134, fig. 19, Poverty Run member, Ohio.
Ectodemites plummeri COOPER, 1946, p. 103, pl. 15, figs. 40–42, Ferdinand limestone, Indiana.

Description.—In lateral view: carapace subrectangular; dorsal and ventral borders straight to slightly concave, nearly parallel; anterior and posterior borders broadly and

evenly rounded, with recurvature into small concavity below anterior cardinal angle of left valve; cardinal angles obtuse. In dorsal view, carapace tumid, blunter posteriorly, with convex lateral borders interrupted by shoulder and node.

Exterior sculpturing consists of posterodorsal shoulder with nearly vertical axis, central amphissitian node above kirkbyan pit, ventral frill, and submarginal ridge. Surface of valves reticulated, with three to four rows of reticulations between submariginal ridge and frill; an incipient carina lies between the frill and node and is lost anteriorly in a series of bifurcations in the rows of reticulations.

Valves subequal. The contact margin of the right valve is interpreted as consisting of selvage, and proximally from it, selvage groove, and list, with weak development of the flange; contact margin of the left valve consists principally of the selvage. Hinge of right valve consists of terminal teeth, a weak flange, and proximally from it, flange groove, selvage, selvage groove, and a weak list continuous with list of the contact margin; hinge of left valve consists of a strong flange curving down and around terminal open sockets, and proximally from the flange, flange groove, and selvage continuous with selvage of contact margin. The strong development of the hinge flange in the left valve effects a reversal of overlap to left over right.

Dimensions.—Averages for five hypotypes (Table 10):

TABLE 10—DIMENSIONS OF *AMPHISSITES ROTHI*

Instar	No. specs.	Length, mm.	Height, mm.	Width, mm.
9	2	0.85	0.49	0.48
9, rt. valve	1	0.89	0.53	
9, left valve	1	0.84	0.52	
8	1	0.76	0.45	0.41

Remarks.—The holotype (Pl. 107, fig. 15) compares very closely with specimens from the Illinois Basin, with similar arrangement of the submarginal ridge, three to four rows of ventral reticulations, frill, recurvature of the dorso-anterior border, and an incipient carina associated anteriorly with bifurcating rows of reticulations. A very closely related species is *Ectodemites plummeri* Cooper which has weaker shoulders, node, and frill, and has a convex ventral border. These differences may not have stratigraphic significance; some specimens of *Amphissites rothi* from the Fulda limestone have immature molts attached to the adult as shown by Cooper (1945) for *Ectodemites plummeri* from the lower Marble Falls limestone.

Types.—Hypotypes: one complete carapace, InGS 301, one right and one left valve, InGS 302, 303; one longitudinal and one transverse (immature) section, InGS 304, 305. Hypotypes from the Fulda limestone, in roadcut Indiana State Route 545, SW¼ NE¼ SW¼ sec. 11. T. 5 S., R. 4 W., Spencer County, Indiana: one immature left valve, InGS 306; one left and one right valve, InGS 315, 316.

AURIKIRKBYA TRISERIATA Shaver, n. sp.
Pl. 107, figs. 16–19; text-fig. 2: 1,2,17,18

Kirkbya kellettae COOPER, 1946, p. 105, pl. 16, figs. 38–42, Wapanucka limestone, Oklahoma.
Knightina kellettae BRADFIELD, 1935, p. 65, pl. 4, fig. 10, Otterville limestone, Oklahoma.

Description.—In lateral view: carapace elongate, subrectangular, with slight posterior convergence of dorsal and ventral borders; dorsal border interrupted by posterior shoulder extending well above hinge line, from which point the posterodorsal border is inclined slightly to the cardinal angle; anterior cardinal angle slightly obtuse; posterior cardinal angle nearly at a right angle. In dorsal view: gross outline symmetrically convex but modified by lateral ridges and marginal frills.

The posterodorsal shoulder extends downward nearly to the frill as an abruptly elevated node-like ridge and is turned sharply anterodorsally, commonly with a constriction at this point, and has a curved extension along the line of midheight and above the kirkbyan pit; near its anterior end, the ridge is turned toward the dorsal border and becomes more gentle. Each valve had along its free border two sharp edged ridges, one interpreted as a submarginal ridge, and proximally from it, a frill. The two ridges converge near the cardinal angles but ventrally are separated by two or three rows of reticulation pits. The inner surface

of the submarginal ridge is set with small transverse ridges. Surface of valves reticulated.

Valves subequal. Right valve overlaps the left except along the hinge. Contact margin of right valve is interpreted as consisting of sharp-edged selvage, and proximally from it, selvage groove and list; selvage modified into simple blunt teeth at the cardinal angles; selvage groove transversely crenulated. Contact margin of left valve consists of selvage which is notched on its distal side just below the cardinal angles, for reception of the teeth of the right valve. Hinge of right valve consists of terminal teeth, selvage, weak flange groove, and posteriorly, flange; selvage groove and list reduced or lacking. Hinge of left valve consists of terminal open sockets, and a sharp ridge (selvage?) overlapping the selvage of the right valve.

Dimensions.—Holotype: length, 0.99 mm.; height, 0.50 mm.; width, 0.49 mm. Averages for four paratypes (Table 11):

TABLE 11—DIMENSIONS OF *AURIKIRKBYA TRISERIATA*

Instar	Length		Height		Width	
	no. specs.	mm.	no. specs.	mm.	no. specs.	mm.
9	4	0.97	4	0.50	3	0.46
8?	1	0.71	1	0.39	1	0.33

Remarks.—Bradfield first described the species as *Knightina kellettae* but allowed such broad interpretation of the genus that no reason remained for separate recognition of *Knightina* Kellett and *Kirkbya* Jones. Kellett (1933) distinguished *Knightina* by the posterior shoulder with no other outstanding surface feature, and *Kirkbya* by its common surface ornamentation of "more or less prominent and distinct nodes and ridges, the most persistent and prominent of which is the (postero) dorsal 'shoulder'." Sohn (1950) distinguished *Aurikirkbya* Sohn from *Kirkbya* by its two well-defined lobes connected ventrally by a ridge; he also interpreted *Kirkbya* as devoid of nodes, ridges, and costae. Sohn further characterized *Aurikirkbya* by its hinge with terminal teeth and open sockets which are lacking from *Knightina*; their absence from *Knightina* distinguishes *Knightina* and *Kirkbya* (Sohn, 1954).

In my opinion, the thinner shell wall along the venter of *Kirkbya canyonensis* Harlton and of Sohn's *Kirkbya* sp. is not consistent basis for removing these species from *Aurikirkbya*; nor is the less prominent lobation of *Kirkbya* sp.

Critical morphology of the Morgantown specimens includes the aurikirkbyan ridges, and hinge with terminal teeth and open sockets but with somewhat rudimentary interangular hinge elements. Clearly, they must be assigned to *Kirkbya* or *Aurikirkbya* following either Kellett or Sohn. In either event, a new specific name is required because of secondary homonymy, and *Kirkbya kellettae* Harlton (assigned to *Aurikirkbya* by Sohn, 1950) has priority over *Knightina kellettae* Bradfield.

Aurikirkbya triseriata, n. sp., *Knightina kellettae*, and *Kirkbya kellettae*, Cooper (not Harlton) differ from *Aurikirkbya kellettae* (Harlton) by having better defined aurikirkbyan ridges and only two or three rows of reticulations between the submarginal ridge and frill. (Compare with five or six rows in Harlton's *Aurikirkbya kellettae*.) Cooper's (1946) *Knightina kellettae* Bradfield is best placed in *Knightina* but is hardly conspecific with Bradfield's type of *K. kellettae*. The new species differs from species of *Aurikirkbya* described by Sohn (1950) in the configuration of the ridge, its slightly simpler hinge, and thinner shell wall along the venter.

Aurkikirkbya triseriata is known only from the Morrow series of the midcontinent and Lower Pennsylvanian of the Illinois Basin; *Aurikirkbya kellettae* is of Missouri age as here restricted.

The specific name is derived from Latin *tri* ("three") and *series* ("row") and refers to the three rows of reticulations between the submarginal ridge and frill as seen in ventral view.

Types.—Holotype, a carapace with frill partially destroyed, InGS 308. Paratypes: one complete carapace, InGS 309; one immature molt, InGS 310; one transverse and one longitudinal section, InGS 311, 312. Hypotypes from the Fulda limestone, Lower Pennsylvanian, in roadcut Indiana State Highway 545, SW¼ NE¼ SW¼ sec. 11,

T. 5 S., R. 4 W., Spencer County, Indiana: one right and one left valve, InGS 313, 314.

REFERENCES

BRADFIELD, H. H., 1935, Pennsylvanian Ostracoda of the Ardmore Basin, Oklahoma: Bull. Am. Paleontology, v. 22, no. 73, 173 p., 13 pls.

COOPER, C. L., 1945, Moult stages of the Pennsylvanian ostracode *Ectodemites plummeri:* Jour. Paleontology, v. 19, p. 368–375, pl. 57.

——, 1946, Pennsylvanian ostracodes of Illinois: Illinois Geol. Survey, Bull. 70, 177 p., 21 pls.

CORDELL, R. J., 1952, Ostracodes from the Upper Pennsylvanian of Missouri. Part I: The family Bairdiidae: Jour. Paleontology, v. 26, p. 74–112, pls. 17–20.

HARLTON, B. H., 1929, Some Upper Mississippian (Fayetteville) and Lower Pennsylvanian (Wapanucka-Morrow) Ostracoda of Oklahoma and Arkansas: Am. Jour. Sci., ser. 5, v. 18, p. 254–270, pls. 1,2.

——, 1933, Micropaleontology of the Pennsylvanian Johns Valley shale of the Ouachita Mountains, Oklahoma, and its relationship to the Mississippian Caney shale: Jour. Paleontology, v. 7, p. 3–29, pls. 1–7.

JOHNSON, W. R., 1936, The Ostracoda of the Missouri series in Nebraska: Nebraska Geol. Survey, Paper 11, p. 1–52, 5 pls.

JONES, T. R., & KIRBY, J. W., 1885, Notes on the Paleozoic bivalved Entomostraca. No. 22. On some undescribed species of British Carboniferous Ostracoda: Annals Mag. Nat. History, ser. 5, v. 18, p. 249–269, pls. 6–9.

——, 1892, Notes on the Paleozoic bivalved Entomostraca. No. 30. On Carboniferous Ostracoda from Mongolia: Annals Mag. Nat. History, ser. 6, v. 9, p. 302–307, pl. 16.

——, 1895, Notes on the Paleozoic bivalved Entomostraca. No. 32. Some Carboniferous Ostracoda from Yorkshire: Annals Mag. Nat. History, ser. 6, v. 16, p. 452–460, pl. 21.

KELLETT, B., 1933, Ostracodes of the Upper Pennsylvanian and Lower Permian strata of Kansas: I. The Aparchitidae, Beyrichiidae, Glyptopleuridae, Kloedenellidae, Kirkbyidae, and Youngiellidae: Jour. Paleontology, v. 7, p. 59–108, pls. 13–16.

——, 1934, Ostracodes from the Upper Pennsylvanian and the Lower Permian strata of Kansas: II. The genus Bairdia: Jour. Paleontology, v. 8, p. 120–138, pls. 14–19.

MCLAUGHLIN, K. P., 1952, Microfauna of the Pennsylvanian Glen Eyrie formation, Colorado: Jour. Paleontology, v. 26, p. 613–621, pls. 82, 83.

MARPLE, M. F., 1952, Ostracodes from the Pottsville series in Ohio: Jour. Paleontology, v. 26, p. 924–940, pls. 133–135.

PAYNE, K. A., 1937, Pennsylvanian Ostracoda from Sullivan County, Indiana: Jour. Paleontology, v. 11, p. 276–288, pls. 38–40.

SHAVER, R. H., 1958, A study of *Pseudobythocypris pediformis*, a new name for an old ostracod: Am. Midland Naturalist, v. 59, no. 1, p. 120–137.

SOHN, I. G., 1950, Growth series of ostracodes from the Permian of Texas: U. S. Geol. Survey, Prof. Paper 221-C, p. 33–43, pls. 7,8.

——, 1954, Ostracoda from the Permian of the Glass Mountains, Texas: U. S. Geol. Survey, Prof. Paper 264-A, 34 p., 5 pls.

WARTHIN, A. S., JR., 1930, Micropaleontology of the Wetumka, Wewoka, and Holdenville formations: Oklahoma Geol. Survey, Bull. 53, 95 p., 7 pls.

MANUSCRIPT RECEIVED OCTOBER 7, 1958.

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 793–808, PLS. 108–111, SEPTEMBER, 1959

MIDDLE DEVONIAN AULOPORID CORALS FROM THE TRAVERSE GROUP OF MICHIGAN

J. LLOYD WATKINS
Midwestern University, Wichita Falls, Texas

ABSTRACT—Twenty-five Middle Devonian species of tabulate corals are placed in the family Auloporidae. The species are assigned to the following genera, the last of which is new: *Aulocystis*, *Aulopora*, *Syringopora*, and *Pachyphragma*. The descriptions include fourteen species of *Aulocystis*, nine of which are new; six species of *Aulopora*, three of which are new; two species of *Syringopora*, one of which is new; and three species of *Pachyphragma*, two of which are new.

INTRODUCTION

THE object of this study is to describe the species of auloporid corals from the Traverse group of Michigan and to compare these species with forms that occur in beds of equivalent age in northern Ohio, southwestern Ontario, and western New York. Most of the material used in this study was obtained from the extensive collections of the Museum of Paleontology, University of Michigan. The author also used material which was collected by him during the summers of 1956 and 1957 from localities in Michigan, Ontario, and New York.

Unless otherwise stated, the types described in this paper are in the Museum of Paleontology, University of Michigan. Locality numbers (p. 806) refer to the official locality list of the Museum of Paleontology.

ACKNOWLEDGMENTS

I wish to thank the following individuals for the loan of type specimens used in this study: Dr. E. R. Eller of the Carnegie Museum, Dr. E. T. Tozer of the Geological Survey of Canada, Dr. A. K. Miller of the State University of Iowa, Dr. M. F. Marple of the Geological Museum of Ohio State University, Mr. John K. Pope of the University of Cincinnati, Dr. Carl O. Dunbar of th Yale Peabody Museum, and Dr. Norman D. Newell of the American Museum of Natural History. I am especially grateful to Dr. Erwin C. Stumm and Dr. G. M. Ehlers for their many helpful suggestions, to Mr. Herbert Wienert for his expert advice on photography, and to my wife, Dorothy, for typing the manuscript.

PREVIOUS WORK

Alexander Winchell (1866) in his list of new species of fossils from the Traverse group in the Little Traverse Bay region described six species of auloporid corals from the Gravel Point formation and Charlevoix limestone. In describing the fossil corals of Michigan, Carl Rominger (1876) named a new species of *Aulopora* from the Potter Farm formation near Alpena, Michigan. No other work was done on this group until Mildred Adams Fenton (1937) described two new species of *Aulopora* from the Gravel Point formation in the Petoskey region and restudied the types of Winchell's species.

When the present study was undertaken only seven valid species of auloporid corals had been described from the Traverse group, and all but one of these species had come from the Gravel Point formation. Since every formation in the Traverse group (Warthin and Cooper, 1943) except the Squaw Bay limestone contains numerous auloporid corals, abundant material was available for study.

METHOD OF STUDY

Whenever possible at least ten corallites of each species were sectioned both transversely and longitudinally in order to determine what characters were valid specific indicators. When specimens were very abundant, several dozen corallites were sectioned in order to determine the variablity of any given structure. Specimens and thin sections were studied with a microscope. The wall thickness was determined with an ocular micrometer from thin sections. The diameters of corallites were determined with

a vernier caliper on well preserved, mature corallites.

STRATIGRAPHY OF THE TRAVERSE GROUP

In 1871 Alexander Winchell applied the term "Little Traverse Group" for the section of Middle Devonian rocks exposed in the Little Traverse Bay region in Charlevoix and Emmet counties, Michigan. A. C. Lane (1895) proposed that the prefix "Little" be dropped since the strata crop out in the Grand Traverse Bay region as well as in the Little Traverse Bay region. In 1931 E. R. Pohl divided the 250 feet of strata which comprise the Traverse group in this region into three stratigraphic units. In ascending order these units are the Gravel Point formation, Charlevoix limestone, and the Petoskey formation. Only the upper part of the Traverse group is exposed in the type locality in Charlevoix and Emmet counties. Beds are recognized in the subsurface that correlate with units exposed in the Thunder Bay region in the eastern part of the state.

The Little Traverse Bay region is the westernmost outcrop area in the northern part of the Southern Peninsula of Michigan where Middle and Upper Devonian strata are exposed.

Kelly and Smith (1947) separated the 460 feet of sediments of the Traverse group that crop out in the central part of the state in the Afton-Onaway area in Cheyboygan and Presque Isle counties into seven formations.

The formations that crop out in the eastern part of the state in the Thunder Bay region of Presque Isle and Alpena counties have been described by Warthin and Cooper (1943). Here the Traverse group is divided into eleven formations. Except for the Upper Devonian Squaw Bay limestone, the Traverse group is Middle Devonian. Warthin and Cooper (1943) suggest that the lower boundary of the Traverse group be placed at the base of the Bell shale and the upper boundary be placed at the base of the Upper Devonian black shales.

Although most of the specimens used for this study were collected from the Traverse group of Michigan, many specimens from beds equivalent in age to those of the Traverse group were collected from the following formations: the Silica shale, Ten Mile Creek dolomite, and Plum Brook shale of northern Ohio: the Arkona shale, Hungry Hollow formation, Widder shale, and Ipperwash limestone in southwestern Ontario; and the Centerfield limestone and Wanakah shale of western New York. See Cooper (1942) for the correlation of these formations.

TAXONOMY OF THE FAMILY AULOPORIDAE

Compound tabulate corals with trumpet-shaped or cylindrical corallites that form dendroid, phaceloid, or reptant coralla are typical of the family Auloporidae. Tabulae are present in most forms and are horizontal, concave, or convex. Septa are represented by spines, spinules, or peripheral ridges. The walls are typically solid. The family is divided into two subfamilies on the presence or absence of transverse connecting tubes.

Hill and Stumm (1956) placed 25 genera in the family. In this paper five genera are discussed, one of which is new. The definition of the family is slightly amended so that forms with a few irregularly spaced pores can be included. The family ranges from the Silurian through the Permian.

SYSTEMATIC DESCRIPTIONS

Phylum COELENTERATA
Class ANTHOZOA
Subclass ZOANTHARIA
Order TABULATA
Family AULOPORIDAE

Auloporidae Milne-Edwards and Haime, 1851, p. 310.

Description.—Coralla compound, dendroid to phaceloid or reptant; corallites cylindrical or trumpet-shaped, increasing by lateral gemmation; some forms connected by transverse stolons; walls typically solid; mural pores rare; walls covered by transversely wrinkled epitheca. Septa represented by spines, peripheral ridges, or by spinules; tabulae horizontal, convex, or concave; closely or widely spaced, broken into tabellae in some forms. Cysts present only in two genera. Sil.-Perm.

Subfamily AULOPORINAE

Aulporidae Milne-Edwards and Haime, 1851, p. 310.

Auloporinae Milne-Edwards and Haime, Hill and Stumm, 1956, p. F469.

Description.—Coralla reptant or erect, small to large; corallites trumpet-shaped or cylindircal, increase by lateral gemmation, producing uniserial, biserial, multiserial, or ramose growth forms; transverse stolons absent. Septa represented by peripheral ridges or rows of spinules, absent in some forms; tabulae present or absent. Cysts present only in one genus. Sil.-Perm.

Genus AULOCYSTIS Schlüter

Aulocystis Schlüter, 1885, p. 148–151.
Drymopora Davis, 1887, pls. 71–72, not. pl. 70.
Ceratopora Grabau, 1899, p. 414.

Type species.—By monotypy, *Aulocystis cornigera Schlüter*, 1885, p. 148–151; 1899, p. 162–165, pl. 16, figs. 8,9 (see pl. 108, figs. 1–3).

Generic diagnosis.—Coralla free growing or attached; ramose dendroid, or reptant; corallites trumpet-shaped, small; rarely over 30 mm. long, less than 10 mm. in diameter; annulated; one or more offsets per corallite. Septa represented by rows of spines or spinules; tabulae absent; cysts always present and well developed; spines on cysts in various degrees of development. Wall thickness ranging from 0.15 to 1.5 mm.; calices circular or oval, very deep, funnel-shaped; a few pores scattered on walls of some corallites.

Remarks.—The species of *Aulocystis* can be divided roughly into two groups. One group has a reptant or dendroid corallum with mature corallites 4.5 mm. or greater in diameter. The second group has a reptant or ramose corallum with mature corallites less than 4 mm. in diameter.

Occurrence.—Devonian.

AULOCYSTIS MULTICYSTOSA, n. sp.
Pl. 108, figs. 4–6

Description.—Corallum probably dendroid; only isolated trumpet-shaped corallites preserved; epitheca with concentric wrinkles; diameters of corallites ranging from 4.2 to 5.1 mm.; mean diameter of 19 corallites 4.6 mm.; wall thickness about 0.4 mm.; cysts numerous, elongate to subglobose; spines on cysts and walls, few to numerous, typically small. The specific name refers to the numerous cysts on the walls.

Remarks.—The numerous, closely spaced cysts and short spines are distinctive features of this species. Several hundred specimens were collected.

Occurrence.—*Aulocystis multicystosa* is found throughout the Bell shale at localities 31, 38, and 55.

Types.—Holotype 34920; paratypes nos. 34921–34923. Locality 50 is the type locality.

AULOCYSTIS CRASSIMURATA, n. sp.
Pl. 108, figs. 7–10

Description.—Corallites trumpet-shaped, solitary; epitheca coarsely annulated; wall thickness about 1.3 mm.; diameters of corallites ranging from 5 to 8.6 mm.; mean diameter of ten corallites 6.3 mm.; cysts elongate and numerous; a few short spines on walls and cysts. The specific name refers to the thick walls.

Remarks.—The very thick walls are characteristic of this species. About twenty specimens were collected.

Occurrence.—*Aulocystis crassimurata is* found only in the middle part of the Bell shale at locality 55.

Types.—Holotype 34924; paratype 34925.

AULOCYSTIS MAGNISPINA, n. sp.
Pl. 108, figs. 11–13

Description.—Externally similar to *Aulocystis multicystosa*; diameters of corallites ranging from 5.1 to 6.4 mm.; mean diameter of fifteen corallites 5.6 mm.; wall thickness about 0.45 mm.; spines on walls and cysts very numerous and typically over 1 mm. in length; cysts numerous and elongate. The specific name refers to the large spines.

Remarks.—The very numerous, well developed spines are characteristic of this species. Specimens from the Rockport Quarry limestone are poorly preserved and yield poor thin sections. Several hundred specimens were collected from the Ferron Point formation.

Occurrence.—This species is found in the Ferrron Point formation at localities 29, downstream from 30, 38; and in the Rockport Quarry limestone at locality 38.

Types.—Holotype 34926; paratypes 34927–34929, 35009, and 35011. Locality 38 is the type locality, Ferron Point formation.

AULOCYSTIS JACKSONI (Grabau)
Pl. 108, figs. 14–15; pl. 109, figs. 1–3

Ceratopora jacksoni Grabau, 1899, p. 415, pl. 1, fig. 1; pl. 2, figs. 6–10; Stewart, 1927, p. 20–21, pl. 1, fig. 6.

Description.—Corallum dendroid; most specimens consisting of isolated trumpet-shaped corallites; epitheca with coarse concentric wrinkles and longitudinal ridges; mean diameters of corallites from various localities ranging from 5.7 to 7.4 mm.; wall thickness ranging from 0.3 to 0.4 mm.; cysts thick or thin, usually widely spaced, elongate to subglobose; spines few to numerous, with a maximum length of 1 mm.

Remarks.—The development of spines and cysts is variable.

Occurrence.—*Aulocystis jacksoni* is found in the Silica shale of northern Ohio; the Ferron Point formation, loc. 38; the Dock Street clay member of the Four Mile Dam formation, locality 53; Four Mile Dam formation, locality 41; Petoskey formation, locality 21; Hungry Hollow formation and Widder shale near Thedford, Ontario; and the Wanakah shale and Centerfield limestone of western New York.

Types.—Holotype 16840, Columbia University; paratype 5654, Yale Peabody Museum; hypotypes 34930 and 35395.

AULOCYSTIS ALECTIFORMIS (Winchell)
Pl. 108, figs. 20–24

Syringopora alectiformis Winchell, 1866, p. 90.
Cyathophyllum ? partitum Winchell, 1866, p. 90.

Description.—Corallum reptant or dendroid; epitheca on well preserved specimens with coarse concentric rings and faint vertical ridges; mean diameter of twelve specimens from Gravel Point formation 6.8 mm.; average wall thickness 1 mm.; mean diameter of eight specimens from Alpena limestone 6.3 mm.; diameters ranging from 5.5 to 8.4 mm.; average wall thickness about 0.9 mm. Cysts thin to rather thick, elongate, usually widely spaced; a few small spines on walls and cysts.

Remarks.—The species is similar to *Aulocystis crassimurata* but differs in having thinner walls and better developed spines. About thirty corallites were studied. The holotype of *Cyanthophyllum? partitum* was sectioned (pl. 108, fig. 23). This species is conspecific with *A. alectiformis*.

Occurrence.—*Aulocystis alectiformis* occurs in the Gravel Point formation, zone 6, beds 1 and 3 of E. R. Pohl (1930), at localities 9, 14c, 14e, and 19; and in the Alpena limestone, one foot shale bed, 20 feet above base, and shaly flank beds of bioherms in upper 5 feet of formation.

Types.—Holotype 14303; hypotypes 24055 and 34939.

AULOCYSTIS ALECTIFORMIS REPTATA,
n. subsp.
Pl. 108, figs. 27–29

Description.—Corallum reptant or dendroid; unweathered specimens with concentric wrinkles and vertical ridges on epitheca; diameters of corallites ranging from 4.8 to 7.5 mm.; mean diameter of four corallites 4.8 mm.; wall thickness ranging from 0.5 to 0.8 mm.; mean wall thickness of four specimens 0.66; cysts rather closely spaced, thin and elongate; spines numerous and long.

Remarks.—The subspecies differs from *Aulocystis alectiformis* in having thinner walls and more abundant and longer spines. About twelve specimens were collected.

Occurrence.—*Aulocystis alectiformis reptata* is found in the Genshaw formation at localities 28, 51, and 58.

Types.—Holotype 34932; paratype 34938. Locality 58 is the type locality.

AULOCYSTIS ALECTIFORMIS DUBIA,
n. subsp.
Pl. 108, figs. 25–26

Description.—Corallites embedded in limestone, all data obtained from thin sections; diameters of corallites ranging from 5.4 to 5.7 mm.; wall thickness about 0.68 mm.; cysts rather numerous, thin to thick, elongate; spines rare, but when present with a maximum length of 0.5 mm.

Remarks.—The subspecies differs from other thick-walled forms of *Aulocystis* by being less spinose. Possibly more complete data can be obtained when better preserved specimens are found. Only a few specimens were collected.

Occurrence.—*Aulocystis alectiformis dubia* is found only in the Newton Creek limestone at locality 40.

Types.—Holotype 34935.

AULOCYSTIS STUMMI, n. sp.
Pl. 108, figs. 16–19

Description.—Corallum phaceloid to dendroid; epitheca with well developed concentric rings and faint vertical ridges; mean diameter of eight corallites 5.9 mm.; diameters ranging from 5.3 to 6.3 mm.; wall thickness about 1.1 mm. Cysts numerous, elongate, tending to be thin; spines numerous with a maximum length of 1 mm.

Remarks.—This is the only thick-walled species of *Aulocystis* that has numerous, long spines. Twelve specimens were studied. This species in named in honor of Dr. Erwin C. Stumm, Professor of Geology at the University of Michigan.

Occurrence.—*Aulocystis stummi* is found only in the Norway Point formation at locality 41.

Types.—Holotype 34940; paratype 35396.

AULOCYSTIS PARVA, n. sp.
Pl. 108, figs. 30–32

Description.—Corallites solitary, no complete corallum found; epitheca coarsely wrinkled. vertical ridges prominent; diameters of corallites ranging from 4.5 to 6.2 mm.; mean diameter of six specimens 5 mm.; wall thickness about 1.1 mm.; cysts few and widely spaced; spines rare or absent, small when present. The specific name refers to the small size of the corallites.

Remarks.—*Aulocystis parva* differs from other thick-walled species of *Aulocystis* by having very few cysts and spines. About two dozen specimens were examined.

Occurrence.—This species occurs in the Petoskey formation at locality 18b and in the Potter Farm formation at locality 68.

Types.—Holotype 34941; paratypes 34942 and 35404. Locality 18b is the type locality.

AULOCYSTIS ALPENENSIS, n. sp.
Pl. 108, figs. 33–35

Syringopora nobilis Billings, Rominger, 1876, p. 85, pl. xxxii, lower tier, center.

Description.—Corallum phaceloid; most specimens consisting of individual corallites; epitheca concentrically wrinkled and with weakly developed longitudinal ridges; diameters of corallites ranging from 4.3 to 6.4 mm.; mean diameter of thirteen corallites from Potter Farm formation 4.7 mm.; wall thickness about 0.4 mm. Specimens from Petoskey formation with mean diameter of 5.2 mm. and wall thickness 0.45 mm.; cysts very numerous, thin and closely spaced; spines typically numerous and well developed, rare in some specimens. The specific name refers to the city of Alpena, Michigan, where several specimens were collected.

Remarks.—*Aulocystis alpenensis* differs from the varieties of *A. alectiformis* by having thinner walls and more abundant cysts, from *A. jacksoni* by having numerous thin cysts, and *A. nobilis* (Billings) 1858, by having thicker walls and fewer spines.

Occurrence.—The species is found in the Potter Farm formation at localities 37 and 68 and in the Petoskey formation at locality 21.

Types.—Holotype 34949; paratypes 7657, 34934, and 34950–34952. Locality 68 is the type locality.

AULOCYSTIS RAMOSA (Whiteaves)
Pl. 109, figs. 19–22

Roemeria ramosa Whiteaves, 1898, p. 367, pl. 48, figs. 4–5.

Description.—Coralla typically ramose or compressed phaceloid; offsets generally remaining in lateral contact with parent; epitheca with very faint concentric wrinkles; diameters of corallites ranging from 2.9 to 4 mm.; mean diameter of six corallites 3.8 mm.; thickness ranging from 0.2 to slightly over 0.3 mm.; most longitudinal sections exhibiting cysts without spines; in well preserved specimens, numerous small spines projecting from walls and cysts; cysts widely spaced; elongate, thin to thick; a few mural pores present.

Remarks.—Since the internal structures are so poorly preserved, it is difficult to describe accurately the characteristics of this species. If *Aulocystis ramosa* is characterized by having numerous small spines projecting from the walls and cysts, then it is very similar internally to *A. cooperi* from the Silica shale, but differs by having a much larger corallum.

Occurrence.—The species is found in the Arkona shale, near Thedford, Ontario. Several dozen coralla were collected.

Types.—Lectotype (here chosen) the orig-

inal of pl. 109, fig. 19, (Whiteaves, 1898, pl. 48, fig. 5), 3753a, National Museum of Canada; hypotypes 25587 and 34957.

AULOCYSTIS FENESTRATA (Winchell)
Pl. 109, figs. 23–28

Syringopora fenestrata Winchell, 1866, p. 90.
Aulopora serpens (?) Goldfuss, Rominger, 1876, p. 87, pl. xxxiii, fig. 2.

Description.—Holotype reptant, typical coralla ramose; epitheca with faint concentric wrinkles; diameters of corallites from Gravel Point formation ranging from 3.0 to 3.6 mm.; mean diameter of five corallites 3.2 mm.; wall thickness about 0.5 mm. Diameters of corallites from Alpena limestone ranging from 3.2 to 4 mm.; mean diameter of five corallites 3.3 mm.; wall thickness slightly less than 0.4 mm. Cysts typically thin, but thick in a few places, elongate, widely spaced; spines rare to absent, small when present.

Remarks.—The thick relatively nonspinose walls and cysts are characteristic features of this species. Six specimens from the Gravel Point formation and several dozen specimens from the Alpena limestone were studied.

Occurrence.—*Aulocystis fenestrata* is found in the Gravel Point formation, zone 6, beds 1 and 3 of E. R. Pohl (1930), at localities 9, 14, and 14c; and in the Alpena limestone, one foot shale bed, 20 feet above the base, loc. 40.

Types.—Holotype 24053; hypotypes 34960, 34963, 34965, and 35407.

AULOCYSTIS FENESTRATA PROBLEMATICA, n. subsp.
Pl. 109, figs. 29–31

Description.—Corallum ramose; epitheca with faint concentric wrinkles; diameters of corallites ranging from 2.8 to 4 mm.; mean diameter of five corallites 3.1 mm.; cysts numerous, elongate, rather closely spaced; spines rare.

Remarks.—The subspecies differs from *Aulocystis fenestrata* in having thinner walls and more abundant cysts. Only two poorly preserved coralla were collected.

EXPLANATION OF PLATE 108

(Exteriors ×1, sections ×3 unless otherwise indicated)

FIGS. *1–3*—*Aulocystis cornigera* Schluter. *1*, exterior of holotype; *2,3*, enlargement of weathered specimens showing internal structures, ×3. Figures after Schlüter (1889).

4–6—*Aulocystis multicystosa*, n. sp. *4*, exterior of holotype 34920; *5,6*, longitudinal and transverse sections of paratypes 34922 and 34923 respectively, Bell shale, loc. 55.

7–10—*Aulocystis crassimurata*, n. sp. *7,8*, exterior of holotype 34924; *9,10*, transverse and longitudinal sections of paratype 34925; Bell shale, loc. 55.

11–13—*Aulocystis magnispina*, n. sp. *11*, exterior of holotype 34926; *12–13*, longitudinal and transverse sections of paratype 34928; Ferron Point formation, loc. 38.

14,15—*Aulocystis jacksoni?* (Grabau). Transverse and longitudinal sections of hypotype 34930; Ferron Point formation, loc. 38.

16–19—*Aulocystis stummi*, n. sp. *16,17*, exterior of holotype 34940; *18,19*, transverse and longitudinal sections of paratype 35396; Norway Point formation, loc. 41.

20–24—*Aulocystis alectiformis* (Winchell). *20,21*, exterior and transverse section of holotype 14303; Gravel Point formation, loc. 14; *22,23*, exterior and transverse section of holotype of *Cyathophyllum* (?) *partitum* Winchell, 24055, Gravel Point formation, SW. ¼ (possibly NW. ¼) sec. 1, T. 34 N., R. 6 W., Emmet Co., Michigan; *24*, longitudinal section of hypotype 34939, Gravel Point formation, zone 6, bed 3 of E. R. Pohl (1930), loc. 14e.

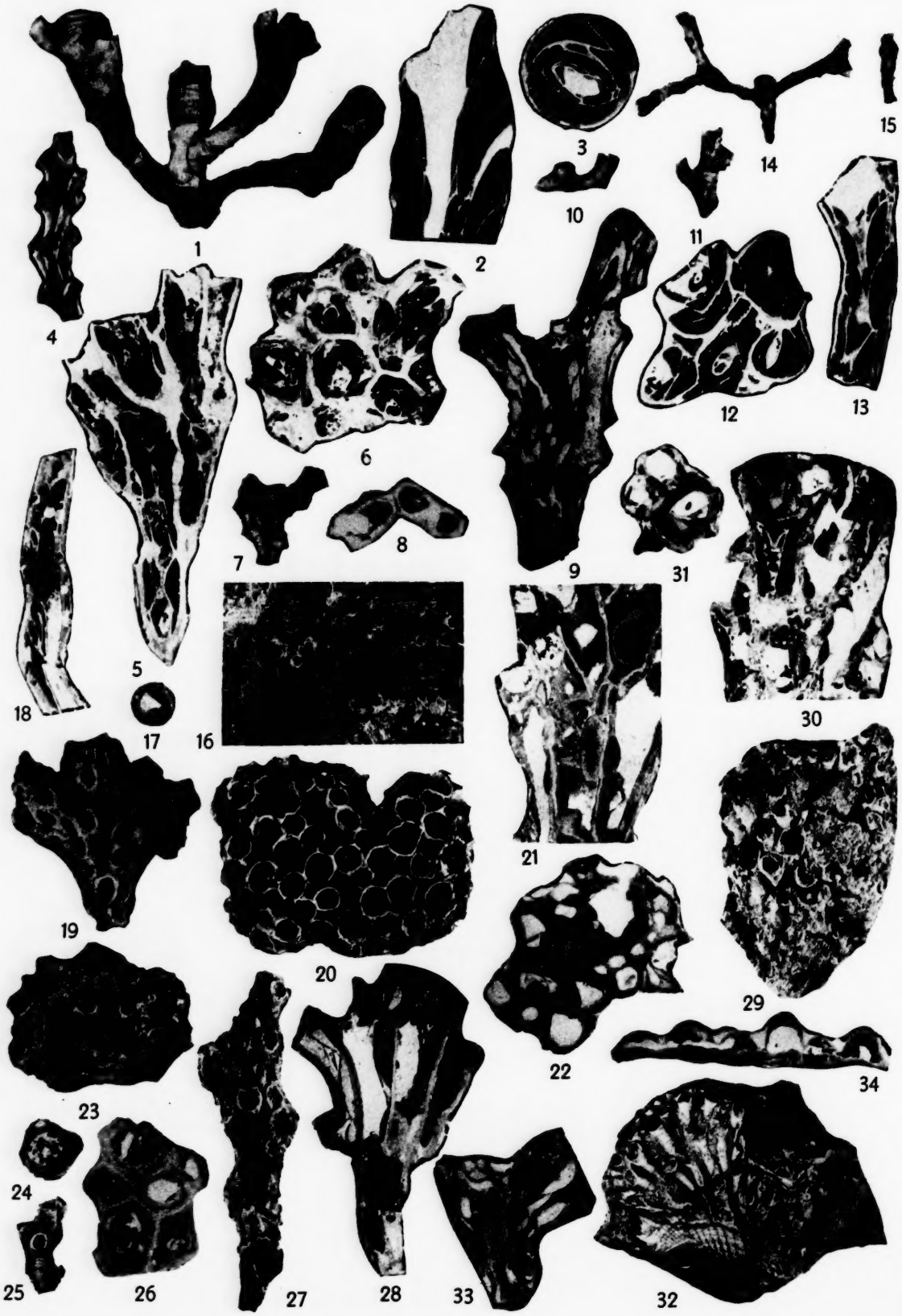
25,26—*Aulocystis alectiformis dubia*, n. subsp. Transverse and longitudinal sections of holotype 34935, Newton Creek limestone, loc. 40.

27–29—*Aulocystis alectiformis reptata*, n. subsp. *27*, exterior of holotype 34932, Genshaw formation, loc. 58; *28,29*, transverse and longitudinal sections of paratype 34938, Genshaw formation, loc. 28.

30–32—*Aulocystis parva*, n. sp. *30*, exterior of holotype 34941; *31,31*, transverse and longitudinal sections of paratype 34942. Petoskey formation, loc. 18b.

33–35—*Aulocystis alpenensis*, n. sp. *33*, exterior of holotype 34949, Potter Farm formation, loc. 37; *34,35*, transverse and longitudinal sections of paratypes 34951 and 34952, Potter Farm formation, loc. 68 and 37 respectively.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34

Occurrence.—*Aulocystis fenestrata problematica* is found in the Genshaw formation at localities 50 and 51.

Types.—Holotype 34967; paratypes 34506 and 34968. Locality 50 is the type locality.

AULOCYSTIS COMMENSALIS, n. sp.
Pl. 109, figs. 32–34

Aulopora tubaeformis Goldfuss, Grabau, 1899, p. 132, fig. 16.

Description.—Coralla attached to specimens of the spiriferid brachiopod *Spinocyrtia granulosa*, generally growing from posterior to anterior part of brachial valve; corallites typically in lateral contact; apertures circular or oval; diameters of corallites ranging from 2.5 to 3.5 mm.; mean diameter of six corallites 3.1 mm.; cysts thin, widely spaced, and elongate; spines rare to absent; epitheca with faint concentric wrinkles.

Remarks.—Although the coralla externally resemble those of several species of *Aulopora*, internally the coralla have cysts that are typical of *Aulocystis*. In the Norway Point formation it is difficult to find a specimen of *Spinocyrtia granulosa* that does not have this species encrusting it. Ten coralla were studied. The specific name refers to a possible commensal relationship which might have existed between the coral and the brachiopod.

Occurrence.—*Aulocystis commensalis* is found in the Norway Point formation at localities 41, 46, and 47; in the Ipperwash limestone, near Thedford, Ontario; and in the Wanakah shale of western New York.

Types.—Holotype 34969; paratypes 34970 and 34971. Locality 41 is the type locality, Norway Point formation.

AULOCYSTIS COOPERI, n. sp.
Pl. 109, figs. 4–6

Ceratopora flabellata Greene, Stewart, 1927, p. 20, pl. 1, fig. 5.

Description.—Coralla uniserial, beserial,

EXPLANATION OF PLATE 109

(Exteriors ×1, sections ×3)

FIGS. *1–3*—*Aulocystis jacksoni* (Grabau). *1*, exterior of holotype 16840, Columbia University; *2,3*, longitudinal and transverse sections of hypotype 7509. Wanakah shale, Eighteen Mile Creek, western New York.

4–6—*Aulocystis cooperi*, n. sp. *4*, exterior of holotype 35399, Potter Farm formation, loc. 68; *5,6*, longitudinal and transverse sections of paratype 34992, Four Mile Dam formation, loc. 47.

7–9—*Aulocystis minuta*, n. sp. *7*, exterior of holotype 34975; *8,9*, transverse and longitudinal sections of paratype 34976. Highest beds of Petoskey formation, loc. 7b.

10–15—*Aulocystis dichotoma* (Grabau). *10,11*, exteriors of two incomplete coralla, hypotypes 34972 and 34973 respectively; *12,13*, transverse and longitudinal sections of hypotype 34975. Widder formation, Jim Bell's Quarry, near Thedford, Ontario. *14*. exterior of lectotype (here chosen) 5741, Yale Peabody Museum; *15*, exterior of lectotype (here chosen) of *A. distorta*, 5743, Yale Peabody Museum. Limestones of Hamilton age at Canandaigua Lake, New York.

16–18—*Aulocystis minuta parallela*, n. subsp. Exterior, transverse and longitudinal sections of holotype 34980, highest beds of Petoskey formation, loc. 7b or 7c.

19–22—*Aulocystis ramosa* (Whiteaves). *19*, exterior of lectotype (here chosen) 3753a, National Museum of Canada, Arkona shale, Township of Bosanquet, Ontario; *20*, exterior of hypotype 25587, Arkona shale, bluffs along Ausable River, 2 miles east and ¾ mile north of Arkona, Ontario; *21,22*, longitudinal and transverse sections of hypotype 34957, 21 feet below top of Arkona shale, Tile Yard, ¼ mile north of Thedford, Ontario.

23–28—*Aulocystis fenestrata* (Winchell). *23,24*, exterior and transverse section of holotype 24053, Gravel Point formation, zone 6, bed 1 of E. R. Pohl (1930), loc. 14; *25,26*, exterior and transverse section of hypotype 34960 and 35407 respectively, Gravel Point formation, zone 6, bed 3 of E. R. Pohl (1930), loc. 9; *27,28*, exterior and longitudinal section of hypotypes 34963 and 34965 respectively, Alpena limestone, one foot shale bed, 29 feet above base, loc. 40.

29–31—*Aulocystis fenestrata problematica*, n. subsp. *29*, exterior of holotype 34967; *30,31*, longitudinal and transverse sections of paratype 34968. Genshaw formation, loc. 51.

32–34—*Aulocystis commensalis*, n. sp. *32*, exterior of holotype 34969; *33,34*, longitudinal and transverse sections of paratypes 34970 and 34971. Norway Point formation, loc. 41.

multiserial, or ramose; uniserial and biserial forms attached, probably giving rise to ramose and multiserial forms; epitheca with faint concentric wrinkles; mean diameter of seven corallites from Four Mile Dam formation 3.5 mm.; wall thickness 0.36 mm.; mean diameter of six corallites from Potter Farm formation 3.1 mm.; wall thickness 0.28 mm.; mean diameter of eight corallites fom Silica shale 3.1 mm.; wall thickness about 0.2 mm.; specimens from the Plum Brook shale with a wall thickness of about 0.38 mm. Cysts widely spaced, elongate, thin to thick; abundant small spines projecting from walls and cysts.

Remarks.—Various authors have referred these specimens to *Aulocystis frutectosa* (Davis) 1887, *A. auloporidea* (Davis) 1887, *A. separata* (Greene) 1902, and *A. flabellata* (Greene) 1902, from the Beechwood limestone of southern Indiana and northern Kentucky. Specimens from the Beechwood limestone are so badly silicified that internal structures are poorly preserved. The specimens from the Traverse group of Michigan and the Silica shale of Ohio were named a new species since the internal structures of similar looking forms from the Beechwood limestone are unknown. Approximately two hundred coralla were collected. The species is named in honor of Dr. G. Arthur Cooper of the National Museum, Washington, D.C.

Occurrence.—*Aulocystis cooperi* occurs in the Plum Brook shale and the Silica shale of northern Ohio; the Dock Street clay, locality 53; the Four Mile Dam formation, locality 47; and the Potter Farm formation, locality 68.

Types.—Holotype 35399; paratypes 34946, 34992, and 35409.

Aulocystis dichotoma (Grabau)
Pl. 109, figs. 10–15

Ceratopora dichotoma Grabau, 1899, p. 418, pl. 2, figs.11–22, pl. 3, figs. 14–16; pl. 4, figs. 1–18.
Ceratopora distorta Grabau, 1899, pl. 3, figs. 1–13.

Description.—Coralla reptant or slightly ramose; corallites trumpet-shaped, typically branching dichotomously; epitheca with faint to coarse concentric wrinkles; median carination present or absent. Average diameter of paratypes 3 mm.; diameters of seven specimens from Widder shale varying from 3.1 to 4.1 mm.; mean diameter 3.4 mm.; wall thickness about 0.2 mm.; paratypes with minute spines in vertical rows on walls of calice; sections of specimens from Widder shale with a few small spines projecting on walls; spines on cysts rare to absent; cysts widely spaced, subglobose, thin to thick.

Remarks.—As defined by Grabau the main difference between *Aulocystis dichotoma* and *A. distorta* was that the latter species lacked a median carination on the surface of the corallite. Examination of the syntypes of both species revealed that this feature may or may not be present in either species. *A. distorta* is here placed in synonymy with *A. dichotoma*. The species differs from *Syringopora intermedia* Nicholson (1874) from the Hungry Hollow formation and Centerfield limestone in being less spinose and having fewer cysts.

Occurrence.—*Aulocystis dichotoma* is found in the upper shales of the Hamilton group in Eighteen Mile Creek and vicinity of western New York (Grabau, 1899), in the limestones of Hamilton age at Canandaigua Lake (Grabau, 1899), and in the Widder shale of western Ontario.

Types.—The original of pl. 109, fig. 14 (Grabau, 1899, pl. 4, fig. 2) is here chosen lectotype, 5741, Yale Peabody Museum. Hypotypes 34972, 34973.

Aulocystis minuta, n. sp.
Pl. 109, figs. 7–9

Description.—Corallum multiserial, compressed; corallites in lateral contact; epitheca with concentric wrinkles; aperatures oval or circular; diameters of corallites ranging from 2.3 to 2.9 mm.; mean diameter of six corallites 2.6 mm.; wall thickness about 0.38 mm.; cysts rather widely spaced, elongate; spines rare to absent. The specific name refers to the small size of the corallites.

Remarks.—Flattened coralla with small corallites is the characteristic feature of this species.

Occurrence.—*Aulocystis minuta* occurs in the highest beds of the Petoskey formation at locality 7b.

Types.—Holotype 34975; paratypes 34976 and 34977.

AULOCYSTIS MINUTA PARALLELA, n. subsp.
Pl. 109, figs. 16–18

Description.—Similar to *Aulocystis minuta* except for phaceloid corallum.

Remarks.—A single, large corallum was collected.

Occurrence.—The subspecies is found only in the highest beds of the Petoskey formation at locality 7b.

Types.—Holotype 34980.

Genus PACHYPHRAGMA, n. gen.

Type species.—*Aulopora erecta* Rominger, 1876, p. 88–89, pl. 33 upper specimen.

Generic diagnosis.—Corallum compound, normal to tight phaceloid; corallites cylindrical; offsets occurring in proximal area; walls thick, ranging from 0.3 to over 1 mm.; composed of concentric or inclined lamellae; tabulae few or numerous, complete or incomplete, arched or depressed; spines on walls in various degrees of development; diameters of corallites from 2.8 to 4 mm.

Remarks.—The genus differs from *Aulopora* in having thick walls, numerous tabulae in places, offsets occurring in proximal region, and a typical phaceloid corallum. It differs from *Romingeria* in lacking umbellate whorls. Since no cysts are present, the genus is easily distinguished from *Aulocystis*.

PACHYPHRAGMA ERECTUM (Rominger)
Pl. 110, figs. 9–16

Aulopora erecta Rominger, 1876, p. 88–89, pl. 33, fig. 4, upper specimen; Stumm, 1947, Card 67.

Description.—Coralla tight phaceloid with cylindrical corallites; commonly encrusting mud balls; epitheca concentrically wrinkled; offset occurring in extreme proximal region; corallite about 3 mm. in diameter; walls about 0.5 mm. thick, composed of inclined lamellae, producing both radial and concentric structures in transverse section (see pl. 110, figs. 7 and 16); blunt projections on walls, common to absent; tabulae numerous, complete or incomplete, concave or convex.

Remarks.—This species is characterized by having walls composed of inclined lamellae, blunt projections on inner walls, and numerous tabulae. Twelve specimens were studied.

Occurrrence.—*Pachyphragma erectum* is found in the Potter Farm formation at locality 68, the Petoskey formation at locality 21, and the Gravel Point formation, zone 6, bed 3 of E. R. Pohl (1930), locality 14e.

Types.—Holotype 8560; hypotypes 25230, 34962, 34999, and 35021.

PACHYPHRAGMA CYLINDRATUM, n. sp.
Pl. 110, figs. 1–4

Description.—Corallum phaceloid with cylindrical corallites; epitheca concentrically wrinkled; walls composed of concentric lamellae; mean diameter of seven corallites from Bell shale 2.4 mm.; wall thickness 0.32 mm.; mean diameter of eight corallites from Ferron Point formation 2.8 mm.; wall thickness 0.37 mm. No tabulae observed; a few small, blunt projections on walls.

Remarks.—Phaceloid coralla with corallites lacking spines and tabulae are distinctive features of this species. About twenty corallites were collected.

Occurrence.—*Pachyphragma cylindratum* occurs in the Bell shale at localities 31 and 38, and in the Ferron Point formation at locality 39.

Types.—Holotype 34933; paratypes 34994–34997. Locality 38 is the type locality.

PACHYPHRAGMA CONCENTRICUM, n. sp.
Pl. 110, figs. 5–8

Description.—Externally similar to *Pachyphragma cylindratum* except for larger corallites; diameters of corallites ranging from 2.8 to 4.3 mm.; wall thickness from 0.48 to 0.7 mm.; tabulae only in proximal portion, concave or convex, complete; spines abundant on walls.

Remarks.—The species differs from *Pachyphragma cylindratum* by having tabulae and numerous spines. Eight coralla were studied.

Occurrence.—*Pachyphragma concentricum* is found in the Ferron Point formation at locality 79; Dock Street clay member of the Four Mile Dam formation, locality 53; Alpena limestone, one foot shale bed, 20 feet above base, locality 40; and in the Gravel Point formation, zone 6, bed 1 of E. R. Pohl (1930), locality 14c.

Types.—Holotype 34998; paratypes 25237, and 35001.

Genus AULOPORA Goldfuss

Aulopora Goldfuss, 1829, p. 82; Fenton and Fenton, 1937, p. 109; Lang, Smith, and Thomas, 1940, p. 24.

Type species.—*Aulopora serpens* Goldfuss, 1829, p. 82, pl. xxix, figs. 1a–d.

Generic diagnosis.—Corallum typically reptant; corallites generally trumpet-shaped dichotomously branching; distal ends turning upward; epitheca with faint concentric wrinkles; septa absent or represented by feeble spines or faint ridges; tabulae typically concave and widely spaced; cysts absent; walls solid.

Remarks.—By definition one can easily distinguish species of *Aulopora* from cyclostomatous Bryozoa belonging to the family Helerelloidea. Bryozoa in this family have perforated walls, while species of *Aulopora* have solid walls. However, in practice, it is very difficult to determine whether the walls are porous or not. In this paper *Aulopora* is treated as a form genus as proposed by Fenton and Fenton in 1937.

Occurrence.—Devonian.

AULOPORA BUCCINATA, n. sp.
Pl. 111, figs. 14–16

Description.—Corallum prostrate, reptant; corallites trumpet-shaped, dichotomously branching; lower surface attached; apertures circular, erect; epitheca annulated; offsets occurring just beneath apertures; scattered minute spines on walls; no tabulae observed; wall thickness slightly over 0.3 mm.; mean diameter of five corallites from Centerfield limestone 4.9 mm.; mean diameter of three corallites from Hungry Hollow formation 5.3 mm. The specific name refers to the trumpet-like appearance of corallites.

Remarks.—*Aulopora buccinata* closely resembles *A.. procumbens* Davis from the Jeffersonville limestone of the Falls of the Ohio, Kentucky, but differs in lacking prominent vertical ridges of spinules in calice.

Occurrence.—*Aulopora buccinata* is found in the Hungry Hollow formation in bluffs along the Ausable River, 2 miles east and ¾ mile north of Arkona, Ontario; and in the Centerfield limestone, 1½ miles west of East Bethany, New York.

Types.—Holotype 35004; paratype 35005. The type locality is 1½ miles west of East Bethany, New York, in the Centerfield limestone.

AULOPORA MICROBUCCINATA, n. sp.
Pl. 111, figs. 21–22

Aulopora serpens Goldfuss, Stewart, 1938, p. 79, pl. 19, figs. 2,3.

Description.—Corallum attached, reptant; corallites trumpet-shaped, branching dichotomously; aperatures erect, circular or slightly oval; diameters of corallites ranging from 2 to 3 mm.; length varying from 4 to 8 mm.; wall thickness about 0.2 mm.; tabulae rare to absent. The specific name refers to the small trumpet-like appearance of corallites.

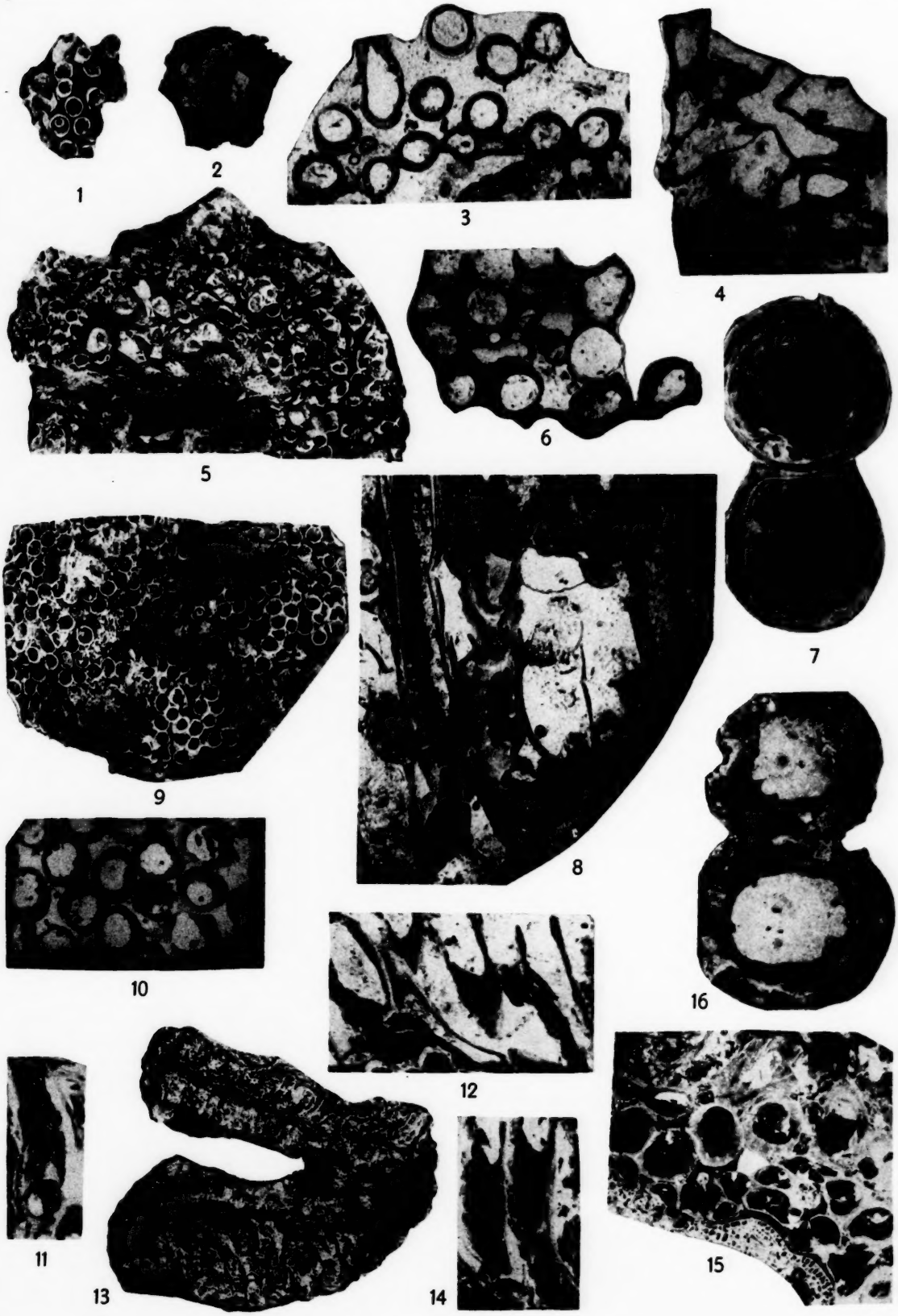
EXPLANATION OF PLATE 110

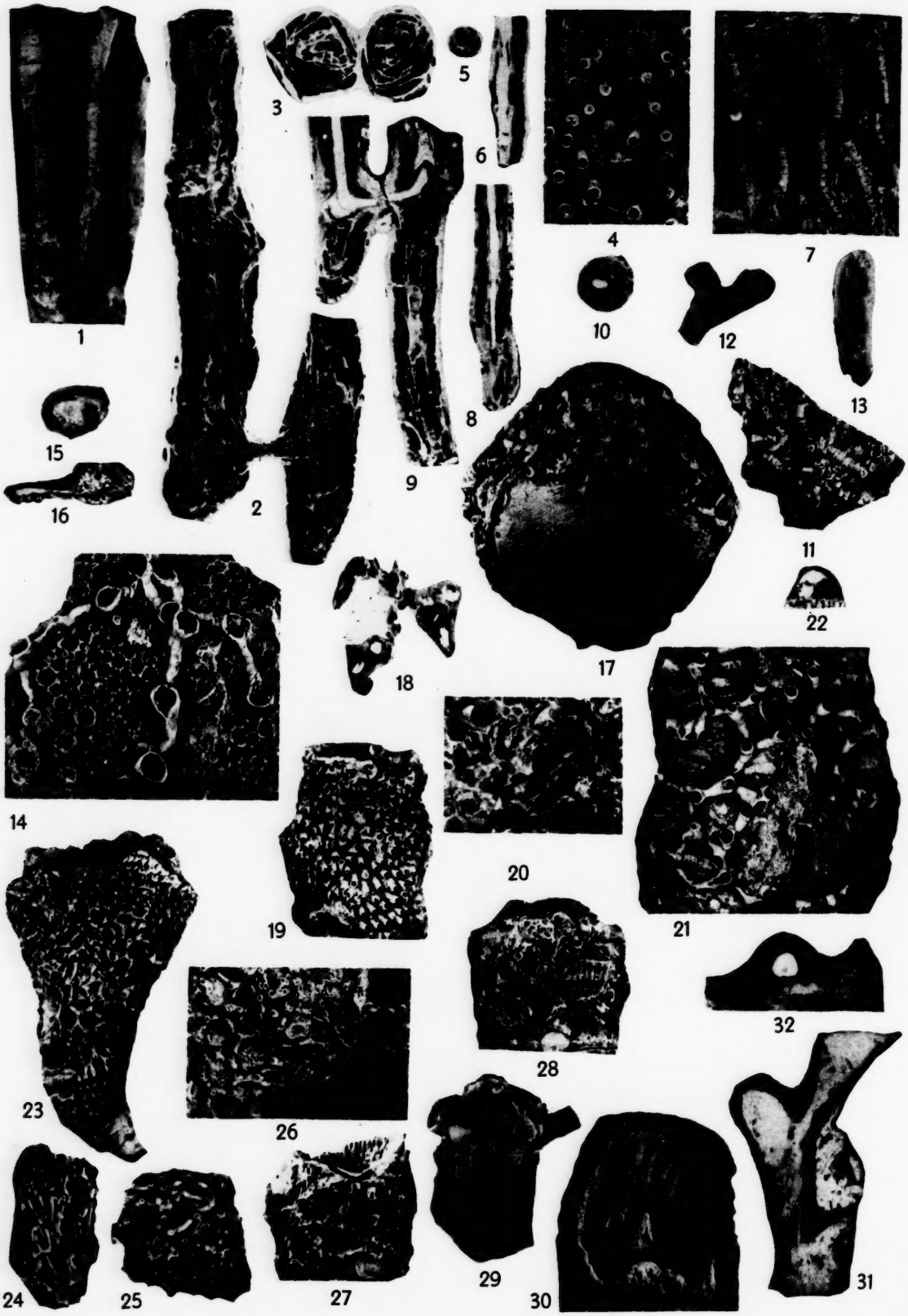
(Exteriors ×1, sections ×3 unless otherwise indicated)

FIGS. *1–4*—*Pachyphragma cylindratum*, n. sp. *1,2*, exterior of holotype 34993; *3,4*, transverse and longitudinal sections of paratype 34997. Ferron Point formation, loc. 38.

5–8—*Pachyphragma concentricum*, n. sp. *5*, exterior of holotype 34998, Alpena limestone, one foot shale bed twenty feet above base, loc. 40; *6*, transverse section of paratype 35001, Dock Street clay, loc. 53; *7*, enlargement of paratype 35001, ×8, showing concentric laminae, Ferron Point formation, loc. 79; *8*, longitudinal section of paratype 35001, Ferron Point formation, loc. 79.

9–16—*Pachyphragma erectum* (Rominger). *9–11*, exterior, transverse and longitudinal sections of holotype 8560, Potter Farm formation, Stony Point, on shore of Lake Huron, just south of Alpena, Michigan; *12*, longitudinal section of hypotype 34999, Potter Farm formation, loc. 89a; *13*, exterior of hypotype 34962, Petoskey formation, loc. 21; *14,15*, longitudinal and transverse sections of hypotype 35021, Petoskey formation, loc. 21; *16*, enlargement of hypotype 25230, ×8, showing concentric and radial structures of laminae, Petoskey formation, loc. 21.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32

Remarks.—The relatively large, trumpet-shaped, dichotomously branching corallites are distinctive features of this species.

Occurrence.—*Aulopora microbuccinata* is found in almost every formation of the Traverse group. It is most abundant in the Bell shale, Ferron Point formation, and Genshaw formation. Several specimens were collected from the Silica shale of northern Ohio.

Types.—Holotype 34956; paratypes 35015, 35106, and 35411. Locality 38 is the type locality, Ferron Point formation.

AULOPORA CRASSATA (Winchell)
Pl. 111, figs. 11–13

Syringopora crassata Winchell, 1866, p. 60.

Description.—Coralla phaceloid, prostrate, or irregular; corallites cylindrical; 1.6 to 1.8 mm. in diameter; with a maximum length of 10 mm.; epitheca coarsely wrinkled; wall thickness about 0.35 mm.; tabulae horizontal, 1 to 2 mm. apart.

Remarks.—The presence of horizontal tabulae and the absence of stolons are characteristic features of the genus *Aulopora*. The species is here placed in that genus. The elongate cylindrical corallites are easily distinguished from other species of the genus.

Occurrence.—*Aulopora crassata* occurs only in the Charlevoix limestone, locality 13.

Types.—Holotype 25054; hypotype 34943.

AULOPORA GREGARIA, n. sp.
Pl. 111, figs. 17,18

Description.—Corallum attached, reptant; corallites trumpet-shaped, branching

---

EXPLANATION OF PLATE 111

(Exteriors ×1, sections ×3 unless otherwise indicated)

FIGS. *1–3*—*Syringopora ehlersi*, n. sp. *1,2*, exterior and longitudinal section of holotype 35555; *3*, transverse section of paratype 35417. Thunder Bay limestone, loc. 35.

4–10—*Syringopora intermedia* Nicholson. *4*, exterior of neotype (here selected) 34982, Hungry Hollow formation, bluffs along Ausable River, 2 miles east and ¾ mile north of Arkona, Ontario; *5*, transverse section of hypotype 34984, Hungry Hollow formation, Ausable River, east of Arkona, Ontario; *6*, longitudinal section of hypotype 35408, Hungry Hollow formation, near Thedford, Ontario; *7,8*, exterior and longitudinal section of hypotypes 34987 and 34986 respectively, Centerfield limestone, cut in Delaware, Lackawanna, and Western Railroad, 1½ miles west of East Bethany, New York; *9,10*, longitudinal and transverse sections of hypotype 34989, Centerfield limestone, 1½ miles east of East Bethany, New York.

11–13—*Aulopora crassata* (Winchell). Exterior, transverse section, and longitudinal section of hypotype 34943, Charlevoix limestone, loc. 13.

14–16—*Aulopora buccinata*, n. sp. *14,15*, exterior and transverse section of holotype 35004, Centerfield limestone, Delaware, Lackawanna, and Western Railroad cut, 1½ miles west of East Bethany, New York; *16*, longitudinal section of paratype 35005, Hungry Hollow formation, bluffs along Ausable River, 2 miles east and ¾ mile north of Arkona, Ontario.

17,18—*Aulopora gregaria*, n. sp. Exterior and transverse section of holotype 35010, Genshaw formation, loc. 51.

19,20—*Aulopora socialis* Fenton. *19*, exterior of holotype 1411, University of Cincinnati, Gravel Point formation, zone 6, bed 1 of E. R. Pohl (1930), loc. 14; *20*, transverse section of hypotype 35020, Gravel Point formation, zone 6, bed 1 of E. R. Pohl (1930), loc. 14.

21,22—*Aulopora microbuccinata*, n. sp. Exterior and transverse section of holotype 34956, Ferron Point formation, loc. 38.

23–28—*Aulopora conferta* Winchell. *23*, exterior of hypotype 35012, Bell shale, loc. 31; *24,25*, exterior of hypotype 35014, Ferron Point formation, loc. 38; *26*, holotype of *A. michiganensis* Fenton, University of Cincinnati, 1409, Gravel Point formation, zone 6 of E. R. Pohl (1930), loc. 14e; *27*, lectotype (here chosen) of *A. cyclopora* Winchell. 25792, Gravel Point formation, shore of Little Traverse Bay, about 2 miles west of Petoskey, Michigan; *28*, holotype of *A. aperta* Winchell, 1430a, Gravel Point formation, loc. 14.

29–32—*Cladochonus antiquus* (Whiteaves). *29*, exterior of lectotype (here chosen) 3751b, National Museum of Canada, Hungry Hollow formation, near Thedford, Lambton County, Ontario; *30*, enlargement of calice of hypotype 35107, ×6.4; *31,32*, longitudinal and transverse sections of hypotype 34978, Hungry Hollow formation, Ausable River Dam near Rock Glen, Ontario.

dichotomously, rarely uniserially, 4 to 7 mm. long; diameters ranging from 1.4 to 1.8 mm.; aperatures circular or oval; wall thickness about 0.2 mm.; offsets occurring just below apertures; tabulae rare, concave; epitheca with faint concentric wrinkles. The specific name refers to the gregarious habit of growth.

Remarks.—*Aulopora gregaria* closely resembles several of Fenton's species of *Aulopora* from the Upper Devonian Hackberry group of Iowa, but differs in such features as angle of bifurcation, shape of coralla, and dimensions of corallites.

Occurrence.—*Aulopora gregaria* is most common in the Genshaw and Four Mile Dam formations. A few specimens occur in the Alpena limestone and Petoskey formation.

Types.—Holotype 35010; paratypes 35412, 35413, and 35017. Locality 51 is the type locality, Genshaw formation.

AULOPORA CONFERTA Winchell
Pl. 111, figs. 23–28

Aulopora conferta Winchell, 1866, p. 91; Rominger, 1876, p. 88, pl. 33, fig. 1.
Aulopora aperta Winchell, 1866, p. 91 (see pl. 111, fig. 28).
Aulopora cyclopora Winchell, 1866, p. 92 (see pl. 111, fig. 27).
Aulopora michiganensis Fenton, 1937, p. 118, pl. 4, figs. 7–8 (see pl. 111, fig. 26).

Description.—Coralla either prostrate and encrusting or phaceloid and erect; corallites trumpet-shaped or cylindrical, apertures erect, circular; offsets occurring just beneath aperatures, usually branching dichotomously, rarely uniserially; epitheca with faint concentric wrinkles. Corallites from 3 to 10 mm. in length; diameters ranging from 0.6 to 1.2 mm.; wall thickness from 0.2 to .3 mm.; tabulae rarely present.

Remarks.—While examining numerous coralla collected from the same locality, the author observed that the shape of the coralla as well as the dimensions of the corallites are highly variable. The characters of the above species are expanded so that variations due to environment can be included under this species. *Aulopora conferta* closely resembles several of Fenton's species of *Aulopora* from the Upper Devonian Hackberry group of Iowa and *Aulopora edithana* Davis (1887) from the Jeffersonville limestone at the Falls of the Ohio, Kentucky, but differs in such details as dimensions of corallites, shape of coralla, and angle of bifurcation.

Occurrence.—*Aulopora conferta* is found in almost every formation of the Traverse group. It is most common in the Bell shale, Ferron Point formation, and Gravel Point formation; less common in the Genshaw formation, Alpena limestone, Four Mile Dam formation, Potter Farm formation, and Petoskey formation. It also occurs in the Hungry Hollow formation of southwestern Ontario.

Types.—Holotype 14301; hypotypes 35012 and 35014.

AULOPORA SOCIALIS Fenton
Pl. 111, figs. 19,20

Aulopora socialis Fenton, 1937, p. 117, pl. 4, figs. 1–5.

Description.—Corallum prostrate, encrusting, ramose; corallites trumpet-shaped to cylindrical, ranging from 1.1 to 1.8 mm. in diameter and from 4 to 5 mm. in length; apertures typically circular; walls 0.2 to 0.3 mm. thick; small spines present in calyx; tabulae rare to absent; epitheca concentrically wrinkled.

Remarks.—The relatively short, stubby corallites with spines in the calices, and an encrusting habit of growth are distinctive features of this species. Three coralla were studied.

Occurrence.—*Aulopora socialis* is found in the Gravel Point formation, zone 6 of E. R. Pohl (1930), locality 14 and 14e.

Types.—Holotype 1411, University of Cincinnati; hypotype 35020.

Genus CLADOCHONUS McCoy

Cladochonus McCoy, 1847, v. 20, p. 227.
Monilopora Nicholson and Etheridge, 1879, p. 293.

Type species.—By subsequent designation of Edwards and Haime, 1850, British Fossil Corals, pt. I, Introd., p. lxxvi, *Cladochonus tenuicollis* McCoy, ibid., p. 227, pl. 11, fig. 8.

Generic diagnosis.—(Hill and Stumm, 1956, p. F472). "Proximal corallites in reptant ring from which free branches arise; individual corallites trumpet- or pipe-shaped, in contact only at points of origin each giving rise to another by lateral increase through wall of the expanded calice; each with a thick peripheral stereozone of

laminar or reticulate sclerenchyme. Septal spines and tabulae lacking in the narrow lumen, but septal ridges may appear in the calices."

Occurrence.—The genus ranges from the Devonian through the Permian.

CLADOCHONUS ANTIQUUS (Whiteaves)
Pl. 111, figs. 29–32

Monilopora antiqua Whiteaves, 1898, p. 364, pl. 48, figs. 1–3a; Grabau, 1899, p. 413.

Description.—Coralla encrusting columns of crinoid stems; cylindrical corallites arising from basal sheath completely encrusting stem; diameters of corallites ranging from 4 to 5.5 mm.; wall thickness ranging from 0.4 to 0.7 mm., composed of concentric lamellae; surface marked by longitudinal ridges separated by grooves or channels; mural pores arranged in vertical rows; rows of pores separated by ridges (see pl. 111, fig. 30); tabulae and spines absent.

Remarks.—The presence of mural pores arranged in vertical rows indicates that this species probably does not belong in the genus *Cladochonus* or the family Auloporidae. The species probably belongs in the genus *Antholites*.

Occurrence.—*Cladochonus antiquus* is found only in the Hungry Hollow formation, near Arkona and Thedford, Ontario.

Types.—Lectotype (here chosen) the original of pl. 111, fig. 29 (Whiteaves, 1898, pl. 48, fig. 1), 3751b, National Museum of Canada; hypotypes 34978 and 35107.

Subfamily SYRINGOPORINAE

Syringoporidae Nicholson, 1879, p. 18,19.
Syringoporinae Nicholson, Hill and Stumm, 1956, p. F472.

Description.—(Hill and Stumm, 1956, p. F472). "Large, erect dendroid or fasciculate coralla composed of cylindrical corallites connected by transverse stolons. Septa represented by peripheral ridges or vertical rows of spines, lacking in some forms. Tabulae typically closely set, numerous, horizontal, infundibuliform, or broken up into tabellae." Sil.-Perm.

Genus SYRINGOPORA Goldfuss

Syringopora Goldfuss, 1826, Petrefacta Germaniae, v. 1, p. 75.

Type species.—By subsequent designation of Edwards and Haime, 1850, British Fossil Corals, p. lxii, *Syringopora ramulosa* Goldfuss, 1826, p. 76, pl. 25, fig. 7.

Generic diagnosis.—(Nicholson, 1879, p. 207). "Corallum commencing as a prostrate network of tubes, which in process of growth sends up numerous vertical corallites. The corallites are cylindrical, arranged with varying degrees of closeness, and each enclosed in a distinct wall. The visceral cavities of contiguous polypes communicates directly by means of a greater or smaller number of hollow horizontal connecting-processes, which in some cases may be nearly or quite obsolete. Tabulae well developed, usually more or less regularly funnel-shaped, and often giving rise to a more or less continuous tube occupying the axis of the visceral chamber. Septa usually slightly developed, spiniform, never lamellar."

Remarks.—Species with few or no stolons are very similar to species of *Aulocystis*, since a few species of *Syringopora* have well developed cysts.

SYRINGOPORA INTERMEDIA NICHOLSON
Pl. 111, figs. 4–10

Syringopora intermedia Nicholson, 1874, p. 126, fig. 58; Stewart, 1938, p. 83, pl. 20, fig. 9.
Ceratopora intermedia (Nicholson), Shimer and Grabau, 1902, p. 167.
Drymopora intermedia (Nicholson), Stumm, 1947, Card 74.

Description.—Corallum reptant with trumpet-shaped corallites; branching dichotomously, or phaceloid with cylindrical corallites; diameters ranging from 2.2 to 3.5 mm.; mean diameter of eleven specimens 2.9 mm.; wall thickness about 0.3 mm.; cysts numerous, thin to thick, elongate; many small spines on walls and cysts. Epitheca with faint concentric wrinkles; stolons rare to absent; no tabulae observed.

Remarks.—A few specimens in the Centerfield limestone have diameters slightly larger than those of typical corallites in the Hungry Hollow formation. Although specimens with stolons were not found in the type locality, a single specimen from the Centerfield does have a stolon (see pl. 111, fig. 9). Abundant material was collected from southwestern Ontario and western New York.

Occurrence.—*Syringopora intermedia* occurs in the Hungry Hollow formation near

Arkona and Thedford, Ontario; in the Centerfield limestone in the vicinity of East Bethany, New York; and in the Ten Mile Creek dolomite and Prout limestone of northern Ohio.

Types.—Since the original types cannot be located, the original of pl. 111, fig. 4 is here selected as neotype, 34982; hypotypes 34984, 34986, 34987, 34989, and 35408.

SYRINGOPORA EHLERSI, n. sp.
Pl. 111, figs. 1–3

Description.—Corallum prostrate with trumpet-shaped corallites, or phaceloid with cylindrical corallites; diameters of corallites ranging from 3.9 to 4.8 mm.; mean diameter of 8 corallites 4.4 mm.; wall thickness about 0.5 mm.; cysts very numerous, closely spaced, thin and elongate; tabellae in a few corallites; numerous small spines on walls, rare on cysts, but when present with a maximum length of 1 mm.; epitheca concentrically wrinkled; transverse stolons in a few specimens.

Remarks.—Young coralla are very similar to species of *Aulocystis*. The species closely resembles *Syringopora meyeri* Loewe (1913) from beds of so-called Hamilton age of Rypeelven, Arctic America, but differs in having numerous, small spines on the walls. *Syringopora ehlersi* is named in honor of Dr. G. M. Ehlers of the Museum of Paleontology, University of Michigan.

Occurrence.—The species is found only in the Thunder Bay limestone at locality 35.

Types.—Holotype 35555, paratype 35417.

LOCALITIES

The localities mentioned in this paper are fossil localities of the Museum of Paleontology, University of Michigan.

7b. Small pits in limestone about 1½ miles north of Norwood, Charlevoix County. Near center of North line, Sec. 27, T. 33 N., R. 9 W., Petoskey formation, upper part.

7c. Ledges and bluffs along Lake Michigan extending from point on shore at locality 7a to point ½ mile north, Charlevoix Co. NE. ¼ Sec. 27 and Sec. ¼ Sec. 22, T. 33 N., R. 9 W. Petoskey formation upper part.

9. Abandoned main (No. 1) quarry of Charlevoix Rock Products Co., about ¾ mile west of Charlevoix, Charlevoix County. SE. ¼ SE. ¼ Sec. 28, T. 34 N., R. 8 W. Gravel Point formation (upper blue shale) and Charlevoix formation, type locality.

13. Abandoned Northern Lime Co., quarry ("Main Curtis and two smaller quarries" of E. R. Pohl), and shore bluffs to west, Emmet and Charlevoix counties near village of Bay Shore SW. ¼ Sec. 6, T. 34 N., R. 6 W. and SE ¼ Sec. 1, T. 34 N., R. 7 W. Charlevoix and Petoskey formations.

14. Quarry of Petoskey Portland Cement Company, about 1½ miles west of Petoskey, Emmet County. SW. ¼ Sec. 2, and SE. ¼ Sec. 3, T. 34 N., R. 6 W. Gravel Point formation, lowermost Charlevoix formation at extreme east end.

14c. Abandoned quarry about 1 mile west of the west end of the Petoskey Portland Cement Company quarry (Locality 14a), and about one-eighth mile south of Little Traverse Bay, Emmet County. NW. ¼ of the NE. ¼ Sec. 9, T. 34 N., R. 6 W. (Rose Quarry, Loc. 42A–F of Grabau, W. E. Smith quarry of R. A. Smith, 1915). Gravel Point formation, strata below upper blue shale.

14e. Abandoned "Bell" quarry and ledges on shore about 2 miles east of Bay shore, Emmet County. Near NE. corner Sec. 8, T. 34 N., R. 6 W. (Rose quarry of Fenton and Fenton, 1930). Basal Charlevoix and upper Gravel Point formations.

18b. Section exposed in 1933 in ditch on east side of Encampment Ave., Bay View, Emmet County, but paved over before 1938. Section extended from termination of Encampment Avenue on U. S. 31 in front of Pennsylvania RR. depot to point about 50 yards south. Separated from top exposure of locality 18a by a covered interval of 300 feet horizontally, 22 feet vertically, and 27 feet stratigraphically. Base of section between 35 and 45 feet above top of Gravel Point formation. Near center of E. line Sec. 32, T. 35 N., R. 5 W. Petoskey formation, beds equivalent to those of Mud Lake quarry, locality 21.

19. Shore of Little Traverse Bay 1 and ½ miles west of mouth of Bear Creek at Petoskey, Emmet County. NW. ¼ Sec. 1 and NE. ¼ Sec. 2, T. 34 N., R. 6 W. Gravel Point formation.

21 Kegomic quarry on south shore of Mud Lake just east of Harbor Springs road (M. 131) about ¼ mile north of its termination on U. S. 31 1 mile east of Bay View, Emmet County. SE. ¼ SW. ¼ Sec. 27, T. 35 N., R. 5 W. Petoskey formation, *Gypidula petoskeyensis* zone and Potter Farm fauna.

23. Beebe School yard and exposures along highway from 2½ to 2¾ miles south of road corner ½ mile west of Afton, Cheboygan County. Extreme SE. corner NE. ¼ and E. line, SE. ¼ Sec. 14, T. 34 N., R. 2 W. Beebe School formation.

28. Ledges below dam on Black River ½ mile NE. of Tower, Cheboygan County. Near center Sec. 3, T. 34 N., R. 1 E. Genshaw formation.

29. Abandoned quarry of Onaway Limestone Company on shore of Black Lake, Presque

Isle County, NW. ¼ Sec. 7, T. 35 N., R. 2 E. Rockport Quarry limestone and Ferron Point shale. Genshaw exposed in slope above quarry.

30. Exposures along Ocqueoc River at Ocqueoc Falls immediately north of main road (U. S. 23, 1940) 4½ miles north of Millersburg, Presque Isle County. Just N. of S. line, Sec. 22, T. 35 N., R. 3 E., Rockport limestone.
31. Quarry of Michigan Limestone and Chemical Company at Calcite, Presque Isle County. Site of Crawford's Marble quarry. 10 sections in SE. part T. 35 N., R. 5 E., and adjacent townships. Dundee and Rogers City limestones and lower Bell shale.
35. Bluffs on northeast shore of Partridge Point, 4 miles south of Alpena, Alpena County. Extends from enter into SE. ¼ Sec. 11, T. 30 N., R. 8 E. Thunder Bay limestone, type locality.
37. Shallow abandoned quarry on Hillman road, about 2 miles west of Alpena Cemetery, Alpena County, SE ¼ of SW. ¼ Sec. 19, T. 31 N., R. 8 E., Alpena County. Potter Farm formation.
38. Abandoned quarry of Kelley's Island Lime and Transport Company. (Great Lakes Stone and Lime Company) at Rockport, Alpena County. Sec. 6, T. 32 N., R. 9 E. Upper Bell shale, Rockport Quarry limestone, lower Ferron Point formation.
40. Quarry of Michigan Alkali Company eastern edge of Alpena, Alpena County. Sec. 13, T. 31 N., R. 8 E. Upper Genshaw formation, Newton Creek limestone, Alpena limestone, type locality.
41. Exposures on banks and in bed of Thunder Bay River below Four Mile Dam, Alpena County. ¼ mile S. of center Sec. 7, T. 31 N., R. 8 E. Other names currently or formerly applied to this dam site are Fletcher Dam, Three Mile Dam, Broadwell's Saw Mill. Four Mile Dam bioherms, type locality, and Norway Point formation.
46. Shale bank on south side of Thunder Bay River on Potter Farm about 1 mile below 4 Mile Dam, Alpena County, Center of E. line Sec. 18, T. 31 N., R. 8 E. Norway Point formation.
47. Exposures on banks and in bed of Thunder Bay River below Norway Point Dam, Alpena County. NE. ¼ Sec. 12, T. 31 N., R. 7 E. This dam is also known currently as the Six Mile or Seven Mile Dam. The waters ponded by the dam cover former dam sites farther up the river in section 2 of the same township, where Trowbridge's Mills, the Boom Company Dam and the original Seven Mile Dam were located (locality 47a). Norway Point formation, type locality.
49. Abandoned quarry of El Cajon Cement Company at El Cajon Beach, Alpena County. Center of W. ½, NE. ¼ Sec. 10, T. 31 N., R. 9 E. Genshaw formation, lower beds.
50. Abandoned shale pit of Alpena Portland Cement Company, about 1 mile east and ⅛ mile north of Genshaw School and 8 miles NE. of Alpena, Alpena County. SE. ¼ Sec. 18, T. 32 N., R. 9 E. Upper Ferron Point formation, type locality and lower Genshaw formation, type locality.
53. Quarry of Thunder Bay Quarries Company, eastern edge of Alpena, Alpena County. SE. ¼ Sec. 14, T. 31 N., R. 8 E. Alpena limestone, Dock Street clay, type section; overlying beds with Four Mile Dam fauna.
55. Cut on private railway of Kelley's Island Lime and Transport Company about one mile south of Bell, Presque Isle County. SE. ¼ SW. ¼ Sec. 24, T. 33 N., R. 8 E. Bell shale, probably near the middle of the formation.
58. Ditches beside road at southern tip of Long Lake, Alpena County. NE. ¼ Sec. 22, T. 32 N., R. 8 E. Genshaw formation, type locality.
68. Small shale pit at the northwest corner of the Alpena Cemetery (Evergreen Cemetery), Alpena County. SW. ¼ Sec. 21, T. 31 N, R. 8 E. Potter Farm formation (part of the type locality?).
77. Ledges on banks of Swan Creek and cut on "New Shore Road" (new U. S. 23), 0.1 mile east of Swan Creek and about 6½ miles southeast of Rogers City, Presque Isle County. NW. ¼ Sec. 17, T. 34 N., R. 6 E. Genshaw formation, lower beds.
79. Road cut and ditch on U. S. 23, 1¾ miles east of Swan Creek and 1 mile west of Trout Creek, about 9 miles southeast of Rogers City, Presque Isle County. Approximately ¼ mile E. of center of Sec. 16, T. 34 N., R. 6 E. Lower Ferron Point shales.

89a. Road cuts and ledges on and near north-south road extending about ¾ mile south from Four Mile Dam (locality 41), Alpena County. N/S line through center Sec. 18, T. 31 N., R. 8 E. Norway Point formation and lower Potter Farm formation, type locality.

Bibliography

Billings, E., 1858, New genera and species of fossils from the Silurian and Devonian formations of Canada: Canadian Naturalist and Geologist, III, (6), p. 419–444.

Cooper, G. Arthur, et al., 1942, Correlation of the Devonian sedimentary formations of North America: Bull. Geol. Soc. America, v. 53, p. 1729–1794.

Cooper, G. Arthur, 1957, Paleoecology of Middle Devonian of Eastern and Central United States: Geol. Soc. America, Memoir 67, p. 249–277.

Davis, W. J., 1887, Kentucky Fossil Corals—a Monograph of Fossil Corals of the Silurian and Devonian Rocks of Kentucky, Part II: Ky. Geol. Survey, xiii+4 p., 139 pls.

Edwards, H. M., & Haime, J., 1850, A Monograph of British Fossil Corals, Part 1, p. i–lxxxv, 1–71, pls. i–xi: Monog. Palaeont. Soc. London.

——, 1851, Monographie des Polypiers fossiles

des Terrains palaeozoiques: Arch. Mus. Hist. Nat. Paris, v. 5, 502 p., 20 pls.

FENTON, C. & L., FENTON, M. A., 1924, The Stratigraphy and Fauna of the Hackberry Stage of the Upper Devonian: Contr. Mus. Geology, Univ. Mich., v. 1, p. 260, pls. I–XIV.

FENTON, M. A., & FENTON, C. L., 1937, *Aulopora:* a Form-Genus of Tabulate Corals and Bryozoans: Am. Midland Naturalist, v. 18, p. 109–115.

FENTON, M. A., 1937, Species of *Aulopora* from the Traverse and Hamilton groups: Am. Midland Naturalist, v. 18, p. 115–119.

GOLDFUSS, G. A., 1826–1829, Petrefacta Germaniae, v. 1, p. 1–76, pls. i–xxv, (1826); p. 77–164, pls. xxvi–l, (1829); Dusseldorf.

GRABAU, A. W., 1899, Moniloporidae, a new family of Palaeozoic corals: Proc. Boston Soc. Nat. Hist., v. 28, p. 409–424, pls. 1–4.

GREENE, G. K., 1902, Contr. to Indiana Paleontology, v. 1, pt. ix, p. 75–86, pls. xxv–xxvii.

HILL, DOROTHY, & STUMM, E. C., 1956, Part F, Coelenterata, Tabulata in Treatise on Invertebrate Paleontology, p. F444–447, University of Kansas Press.

KELLY, W. A., & SMITH, G. W., 1947, Stratigraphy and Structure of Traverse group in Afton-Onaway Area, Michigan: Bull. Am. Assoc. Petroleum Geologists, v. 31, p. 447–449.

LANE, A. C., 1895, The Geology of Lower Michigan: Mich. Geol. Survey, v. 5, pt. 2, p. 24.

LANG, W. D., SMITH, S., & THOMAS, H. D., 1940, Index of Paleozoic Coral Genera: British Mus. Nat. Hist., London, 231 p.

LOEWE, S., 1913, Report of the Second Norwegian Expedition in the "Fram," no. 30, 23 p., vii pls.

MCCOY, F., 1847, On the Fossil Botany and Zoology of the Rocks Associated with the coal of Australia: Ann. Mag. Nat. Hist., (1), xx, p. 145–147,226–236,298–312, pls. ix–xvii.

NICHOLSON, H. A., 1874, Report upon the Palaeontology of the Province of Ontario, p. 1–133, pls. i–viii.

——, 1879, On the Structure and Affinities of the "Tabulate Corals" of the Paleozoic Period, p. xii, 1–342, pls. i–xv, Edinburgh and London.

——, & ETHERIDGE, R., 1879, On the Microscopic Structure of Three Species of the Genus *Cladochonus*, M'Coy: Geol. Mag., n. s. (2), VI, p. 289–296, pls. vii.

POHL, E. R., 1930, The Middle Devonian Traverse Group of Rocks in Michigan, A Summary of Existing Knowledge: Proc. U. S. Natl. Mus., v. 76, no. 2811, 34 p., 2 pls.

ROMINGER, C., 1876, Paleontology, Fossil Corals: Mich. Geol. Survey, v. 3, pt. 2, 161 p., 55 pls.

SCHLÜTER, C., 1885, Ueber einige neue Anthozoen aus dem Devon.: Verhandl. naturhist. Vereines preuss., Rheinlande, Westfalens, etc., Fahrg. 42—Sitz-ber., niederrhein., Gesellsch., Natur- und Heilkunde Bonn, p. 144–151.

——, 1889, Antozoen des rheinischen Mittel-Devon.: Abhandl. Geol. Specialkarte Preuss. Thuring. Staat., VIII, (4), p. x, 259–465, pls. i–xvi.

SHIMER, H. W., & GRABAU, A. W., 1902, Hamilton Group of Ontario: Bull. Geol. Soc. America, v. 13, p. 149–186.

STEWART, G. A., 1927, Fauna of the Silica Shale of Lucas County: Geol. Survey Ohio, (4), Bull. 32, 76 p., 5 pls.

——, 1938, Middle Devonian Corals of Ohio: Geol. Soc. America, Special Paper no. 8, 120 p., 20 pls.

STUMM, E. C., 1947–1950, Tabulata, In Type Invertebrate Fossils of North America (Devonian).

WARTHIN, A. S., & COOPER, G. A., 1943, Traverse Rocks of Thunder Bay Region, Michigan: Bull. Am. Assoc. Petroleum Geologists, v. 27, no. 5, p. 571–595.

WHITEAVES, J. F., 1898, On Some Additional or Imperfectly Understood Fossils from the Hamilton Formation of Ontario, with a Revised List of the Species Therefrom: Contr. Canadian Paleontology. Geol. Survey Canada, v. 1, pt. 5, no. 7, p. 361–436, 3 pls.

WINCHELL, A., 1866, The Grand Traverse Region: Ann Arbor, Mich., Dr. Chase's Steam Printing House, p. 83–97.

——, 1871, Mich. Geol. Survey Rept. Prog., p. 3–64.

MANUSCRIPT RECEIVED DECEMBER 29, 1958

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 809–842, PLS. 112–116, SEPTEMBER 1959

MORE MISSISSIPPIAN BELEMNITES

ROUSSEAU H. FLOWER AND MACKENZIE GORDON, JR.
New Mexico Bureau of Mines, and U. S. Geological Survey[1]

ABSTRACT—New Mississippian belemnites comprise three new genera, containing five named and one unnamed new species. *Eobelemnites?* sp. is from the rocks of Chester age of Alabama. Other species are based upon eight specimens from the Fayetteville shale of Arkansas and more than 250 specimens from the Chainman shale of Utah. The new morphologic terms septal line and neck lobe are proposed. Some of the new forms have phragmocones which are very close to those of true and supposed bactritids, raising the question as to whether some such supposed bactritids may be based upon exfoliated belemnoid phragmocones. Review of features of the Aulacoceratidae indicates that its distinction from the Belemnitidae is not warranted. Details of morphology are discussed, not all of which are explained satisfactorily from the present material, notably, variation of the rostral tips, vesicular structure in the rostrum, thinness of conotheca and absence of a clear protoconch suggesting resorption of protoconch and early phragmocone within the rostrum. Both Belemnitidae and Belemnoteuthidae occur in Permian and Triassic; Mississippian forms are Belemnitidae, but show some diversity of form and structure suggesting an appreciably older derivation of the Coleoidea.

INTRODUCTION

THIS paper is devoted to the description of some additional Mississippian belemnoids, comprising one phragmocone tentatively assigned to *Eobelemnites*, and about 260 specimens that require the recognition of three new genera and five new species. One species is abundant enough to permit the study of its morphology by thin sections. This study has taxonomic and phyletic implications that prompt a reassessment of the origins and the relationship of the Coleoidea, Nautiloidea, and Ammonoidea.

Though belemnoids have been recognized in the Triassic for many years, their presence in older rocks has not been generally admitted until very recently. Actually, de Koninck (1843) figured two belemnoid fragments from Belgium, one from the Viséan, and another from beds of Devonian age at Couvain. For nearly a century this report has been generally ignored or discounted.

Flower (1945) described *Eobelemnites caneyensis* from "a boulder, evidently Mississippian in age, from the Johns Valley (Caney) shale of Oklahoma," a report which has met with scepticism, though no good basis for this incredulity has been expressed. Fischer (1947) refers to this form as "a belemnoid which, according to its label, was collected years ago by Ulrich in a probably Mississippian boulder in Pennsylvanian shale at Johns Valley, Oklahoma." Shimansky (1954) cites Davitashvili (1949) in a general work on paleontology, as an authority on the doubtful age of this specimen, and states that Fischer (1947) believes the form to belong to *Dictyoconites*, a statement which cannot be found in Fischer's paper.

One can only conclude that the lack of wide acceptance which greeted both de Koninck's report and Flower's later description of a Mississippian belemnoid stems from a widely-held conviction that there are no belemnoids as old as the Mississippian; if there were, they should have been found long before this. The present report will show this view to be fallacious.

In recent years it has become evident that the Triassic belemnoids, formerly thought to be the oldest forms, are exceedingly diverse, containing representatives of the Belemnitidae (=Aulacoceratidae) and also of the Belemnoteuthidae. Fischer (1947) has described a species of *Dictyoconites* from the Permian and Rosenkrantz (1946) has described *Permoteuthis*, a new Permian genus attributed to the Belemnoteuthidae. If both the Belemnitidae and Belemnoteuthidae are differentiated as early as Permian time, the presence of coleoids in still earlier strata is to be expected. Indeed,

[1] Publication authorized by the Director, U. S. Geological Survey.

our present observations indicate such variation in form and structure of the Mississippian forms that one may well credit de Koninck's report of a belemnoid in the Devonian, even though his specimen, collected more than a century ago, still remains without a duplicate.

SOURCES OF THE MISSISSIPPIAN BELEMNOIDS

The material upon which the present study is based has proved taxonomically vexing. Various specimens, although quite significant in themselves, show nonhomologous parts of the shell, which make close comparison difficult. Furthermore, it was hard at first to believe that the various successive finds could actually represent a series of species so diverse that it is necessary to recognize three new genera and five new species.

Barely a month after the publication of *Eobelemnites caneyense*, Mr. Frederick F. Mellen of West Jackson, Mississippi submitted for study two crushed phragmocones from the rocks of Chester age of Alabama which he had recognized as possible belemnoid fragments. It was evident that without attached or at least associated rostral fragments, the belemnoid nature of these specimens could not be proved, but it was also evident that these phragmocones conform in general to those of *Eobelemnites caneyense* in their rapid expansion and oblique sutures, and differ in these respects from any known Mississippian orthoconic nautiloids. One of the specimens was lost from Flower's material, then at the New York State Museum, but the other is figured here and described as *Eobelemnites* (?) sp.

The next find came from a collection made by Mr. Roger C. Baker of the U. S. Geological Survey from a locality in the Fayetteville shale near Fayetteville, Arkansas (USNM loc. 3301). One specimen was recognized as a belemnoid by Dr. G. A. Cooper and was submitted to Flower for study. It is a well-preserved rostrum, complete from its tip almost to its anterior end, for anteriorly it was a thin sheath of a conothecal cavity. It has a black polished surface with numerous very fine imbricating longitudinal markings, some broad rounded furrows, and shows a tip which is very faintly curved exogastrically. Prior to sectioning, this shell showed only external features of the rostrum and failed to display the conotheca and phragmocone. Hence it could not be compared in detail with *Eobelemnites* in which the conotheca and phragmocone are well shown, but the surface of the rostrum is not. Sectioning of its anterior end later revealed that the shell differs from *Eobelemnites* in several important characters and it is referred to a new genus *Paleoconus*.

A second specimen from Baker's collection was recognized as a belemnite independently by Gordon. It does not closely resemble either of the others. Its tip is more pointed and more symmetrical; its surface is finely and prominently striate with some striae enlarged into deeper grooves. The anterior end of the specimen originally enclosed a conotheca and, probably, a phragmocone, but this portion is crushed and any original features of the phragmocone which may have been present are destroyed.

Two additional specimens comparable with the preceding specimen were collected by Gordon from the Fayetteville shale near Marshall, Arkansas (USGS loc. 14363). One consists of a rostrum, only slightly flattened, having a conothecal cavity in its anterior end. The second is a tiny portion of a phragmocone showing at its base a septum and some rostral material attached to the wall of the preserved short part of the conotheca. The specimens are evidently conspecific, and might, from their proportions, have come from a single individual. Though these two forms are obviously similar to the preceding one, they have some differences of shape and surface markings of the rostrum which are difficult to interpret as either variation within a species on the one hand, or as possible specific differences on the other.

In the summer of 1954 a contribution to this problem came from an unexpected source, the Chainman shale of western Utah. First two poorly preserved belemnoid fragments were found in this formation in the Needle Range and during the next two days the same formation yielded 113 fragments from the Burbank Hills, an assemblage of specimens which was increased to 250 by further collecting. These are, like the last three Arkansas specimens described, rostra with fine longitudinal striae and

some stronger furrows. The suite of material shows wide variation in shape of the apex in general proportions, and in almost all details of the surface markings, including the spacing and depth of the striae and the number and arrangement of the furrows. Nearly all of the specimens are somewhat crushed, and those which show conothecae at their anterior ends generally exhibit pronounced crushing there, the crushing increasing adorally where the rostrum is thinner and weaker. One specimen, however, or rather two fragments which are believed to have come from a single specimen, preserve an undistorted phragmocone. Other specimens in which distortion of the phragmocone was slight, have served as a basis for study of the internal structure by thin sections. This suite of specimens presented a most puzzling problem at the specific level, but close study has resulted in the conclusion that most of them belong to a single variable species referred to a new genus *Hematites*. The amount of variation shown by the Chainman shale belemnoids is large, and the morphological limits of the species are such that the three striate specimens from the Fayetteville shale of Arkansas cannot be distinguished. Most of these forms are characterized by furrows prominent ventrally, weak dorsally, and with a midventral furrow usually more prominent than the others. A few specimens instead showed no midventral furrow, but two pairs of ventrolateral furrows. These forms are separated as a distinct species, *H. burbankensis*, as distinct from *H. barbarae*.

One more find introduced additional problems. In searching through the older collections of the U. S. Geological Survey, Gordon came upon two lots of material collected from a single locality near Marshall, Arkansas, the first collected by Ulrich and Adams in 1902, (USGS loc. 1625) and the second from the same locality, in 1907 by Girty (USGS loc. 1619). Two of the Arkansas specimens of *Hematites barbarae* came from a lower horizon in the Fayetteville shale at essentially this same locality. The material contained four fragments of phragmocones and one fragment of a living chamber. It was evident that as the phragmocones were strongly compressed, and the living chamber was circular in section, that they had nothing to do with each other; further, the living chamber, though essentially commensurate with the phragmocones, showed a constriction at its base indicating that it was from the anterior end of a living chamber of a small orthoconic nautiloid, the phragmocone of which could not have attained as large a diameter, as those of the associated specimens. The belemnoid phragmocones are strongly compressed in cross section, have sinuate sutures, with rounded ventrolateral crests separated by a V-shaped midventral lobe. In this respect they are obviously distinct from *Hematites*. Their belemnoid nature was shown only by portions of a rostrum adhering to one of the three specimens. They form the basis of the present genus *Bactritimimus*. As the name implies, they mimic the bactritid cephalopods, and particularly those recently described by Shimasky (1954) from the Permian of the Ural Mountains. Indeed it seems highly probable that the Parabactritidae and other supposed Late Paleozoic bactritids with short camerae may actually be belemnoid phragmocones.

Again material is vexing at the specific level. The two best specimens have differences in rate of expansion, depth of septum, nature of the cross section and the septal foramen which require that they be recognized as two distinct species, *B. ulrichi* and *B. girtyi*.

STRATIGRAPHIC DISTRIBUTION OF THE BELEMNOIDS

It is of more than passing interest that, so far as we know, all the Mississippian belemnoids described herein come from a single major goniatite zone, commonly known as the Lower *Eumorphoceras* (E^1) zone. The Arkansas specimens are all from the Fayetteville shale, which in the vicinity of the town of Marshall in Searcy County is the approximate stratigraphic equivalent of the Lower *Eumorphoceras* zone. Near Fayetteville, in Washington County, and near Batesville, in Independence County, the basal part of the Fayetteville shale contains goniatites of the *Goniatites granosus* or Upper *Goniatites* zone, which immediately underlies the Lower *Eumorphoceras* zone. Gordon has completed a study of the Arkansas Carboniferous cephalopods in

which their zonation is discussed in some detail. *Hematites* and *Paleoconus* in Arkansas have been found in the lower shale member of the Fayetteville shale, while *Bactritimimus* occurs in a bed, associated with *Eumorphoceras plummeri* Miller and Youngquist, about a third of the distance down from the top of the formation.

The Utah specimens of *Hematites* come from the middle part of the Chainman shale and are distributed through 402 feet of beds, as determined in a section measured by Gordon in 1957 in the Burbank Hills. These belemnoids are particularly abundant in the upper 100 feet of the zone, 964 to 1064 feet above the base of the Chainman shale, which is about 2290 feet thick in this area. The stratigraphic position of two specimens from the Needle Range is in the same approximate part of the formation.

BELEMNOID COLLECTING LOCALITIES

USNM locality

3301 Washington County, Arkansas. Confluence of two small intermittent streams, 150 yards west by south of a right angle bend in the road at the center of the SE¼ sec. 14, T. 16 N., R. 30 W., 1.7 mile east of U. S. Highway 71-62 and 0.2 mile north of Arkansas Highway 16, on the south slope of Mount Sequoyah (East Mountain), near Fayetteville. Fayetteville shale, roughly 75 feet below the base of the Wedington sandstone member. Collectors, R. C. Baker and N. Payne, 1952, (2 specimens).

USGS localities (Upper Paleozoic locality register)

1619 Searcy County, Arkansas. Hill ½ mile southeast of Marshall. Fayetteville shale, base of 15-foot limestone bed, 80 feet (by barometer) below the top of the formation. Same bed and approximately the same locality as 1625. Collector, G. H. Girty, September 19, 1907, (2 specimens).

1625 Searcy County, Arkansas. Hill ½ mile southeast of Marshall. Fayetteville shale, base of 15 feet of limestone in bed 2 of section. Collectors, E. O. Ulrich amd G. I. Adams, September 1902, (1 specimen).

14363 Searcy County, Arkansas. Just east of U. S. Highway 65 and just outside city limits of Marshall, near base of grade, near the center of sec. 31, T. 15 N., R. 16 W. Fayetteville shale, fossils weathering from 15-foot interval of shale, 22 to 37 feet above the base of the formation. Collectors, M. Gordon, Jr. and R. A. Lewandowski, April 14, 1953, (2 specimens).

15157 Millard County, Utah. Third shale ridge about 200 yards west of desert road, south of gully along which oil company section was measured, probably in the NE¼ sec. 27, T. 25 S., R. 19 W., on the west slope of the Needle Range. Chainman shale, limestone bed in the middle part. Collectors, R. Kopf and I. G. Sohn, August 9, 1954, (2 specimens).

15165 Millard County, Utah. Burbank Range, in a large dry wash about 0.2 mile upstream from where the road enters it, probably in the NE¼ sec. 36, T. 22 S., R. 18 W. Fossils weather out of shale with scattered limestone nodules at the east side of the wash. Chainman shale, roughly 630 feet above the 4-foot limestone marker bed which is 340 feet above the base of the formation. Collectors, B. A. Gordon, M. Gordon, Jr., I. G. Sohn, and R. Kopf, August 10 and 11, 1954, (93 specimens).

15166 Millard County, Utah. Same general locality and stratigraphic interval as 15165 but across a gully and small fault, beginning about 100 yards upslope to the southeast and extending across the ridge for 150 yards in a southerly direction. Collectors, M. Gordon, Jr., I. G. Sohn, and R. Kopf, August 11, 1954, (20 specimens).

17055 Millard County, Utah. Same locality and stratigraphic interval as collection 15165. Collectors, M. Gordon, Jr., R. K. Hose, and R. J. Ross, Jr., June 6, 1957, (20 specimens).

17186 Millard County, Utah. Burbank Range, 0.6 mile up large wash from the point where the road first enters it. Approximately the same stratigraphic interval as 17187, but in the next gully 100 yards to the south and within 100 feet of where the gully intersects the wash. Collectors, M. Gordon, Jr. and R. Christner, September 17, 1957, (1 (specimen).

17187 Millard County, Utah. Burbank Range section, about 0.3 mile south of locality 15165 and 100 yards east of the wash on the flanks of a hill within a large tributary gully. Chaiman shale, 60-foot interval, 1004 to 1064 feet above the base of the formation. Collectors, M. Gordon, Jr. and R. Christner, September 17, 1957, (99 specimens).

17194 Millard County, Utah. Burbank Range section, top and east slope of same hill as that of 17187. Chainman shale, 40-foot interval, 964 to 1004 feet above the base of the formation. Collectors, M. Gordon, Jr. and R. Christner, September 19, 1957, (15 specimens).

17203 Millard County, Utah. Burbank Range section, gully north of that along which section was measured.

Chainman shale, a 4-inch limestone bed 661 feet above the base of the formation. Collectors, M. Gordon, Jr. and R. Christner, September 21, 1957 (2 specimens).

MORPHOLOGICAL NOTES ON BELEMNOID AND NAUTILOID PHRAGMOCONES

Conotheca and Shell Wall

Müller-Stoll (1936) recognized three layers in the conotheca of belemnoids which, together, are known as the *velamen triplex*. They consist of (1) a thick outer layer the *stratum callosum*, which alone of all of the layers bears conothecal striae on its surface, (2) a thin *stratum album* and (3) an inner thin *stratum profundum*. Flower (1945) recognized three possible layers in the conotheca of *Eobelemnites*, which well may correspond to these layers which Müller-Stoll was able to recognize from thin sections. Material of *Eobelemnites* could not be used for thin sections, but it was evident that there was a thick outer layer which bore the conothecal striae on its surface, and probably two thin inner layers which were essentially smooth, or bore only transverse bands of very fine granulations or punctae.

Obviously, the conotheca corresponds to the wall of the nautiloid shell, but from present evidence we cannot trace the origin of the three layers of the conotheca, simply because most fossil nautiloid shells are so replaced that it is impossible to differentiate original shell layers. Some consolation may be sought, however, in the fact that the existence of three shell layers in *Nautilus* has been known for a long time. Several authors have noted the parallel between the three layers of the conotheca and the three layers of a pelecypod shell. If there is any homology it must also be shared by the nautiloids. Yet the nautiloids, which were certainly the ancestors of the belemnoids, are not mentioned, because the three layers corresponding to those of belemnoids or pelecypods are not commonly evident.

Apparently most fossil nautiloids have, as does *Nautilus*, a shell which was dominantly aragonitic, and such materials are commonly found replaced by coarse calcite in such a way that original chemical or textural differences among the layers is completely lost. Though numerous thin sections of nautiloids have been examined by the authors, particularly the senior author, showing shel walls, and embracing representatives of the Ellesmeroceratida, Actinoceratida, Endoceratida, Michelinoceratida, Tarphyceratida and Barrandeoceratida, in no instance has a specimen been encountered which shows more than the faintest indication of original shell structure, and only the faintest indications are found of differentiation of layers. One may, indeed, expect that within an order as varied as the Nautiloidea, that while three layers may be the general, and perhaps even the primitive condition, there may well have been radical departures from this pattern, perhaps paralleling to some extent the wide variation which is already known in internal structures of the shells.

The Septal Line

In the present study some features of the surfaces of phragmocones have been noted which have in the past been the source of some confusion. A short distance anterior to the suture, the belemnoids may show a fine transverse narrowly incised line which parallels the suture in general. For this structure the term *septal line* is proposed. It is particularly well shown on Pl. 113, figs. 1–2 for *Bactritimimus girtyi*.

Two interpretations of this structure are possible, (1) that it may mark the anterior limit of very small, essentially abortive cameral deposits and (2) that it may mark the anterior limit of the mural part of the septum. Fortunately evidence is at hand indicating, if not proving, that the first interpretation is probably the correct one. Before proceeding to a discussion of these structures, it must be noted that a specimen of a cephalopod showing the septa is commonly though actually improperly referred to as an internal mold. A true internal mold is an impression of the interior of a shell, with no shell parts, either in their original condition or as replacements. Cephalopod phragmocones, however, have incorporated in them the free parts of the septa and siphuncle and may contain siphonal and cameral deposits. Furthermore, and most significant for the present discussion, their surfaces may be true impressions of the inner surface of the camera walls, or some parts of the shell may be incorporated in them.

The part most commonly found included

in an "internal mold" of this type is the mural part of the septum. As originally defined, the mural part of the septum was supposed to continue forward from the free part of the septum with which it is continuous, orad to the suture of the next adoral septum (Teichert, 1933). However, this condition cannot always be demonstrated. Some nautiloids show the mural part of the septum as an extremely thin structure, and one which becomes gradually thinner as it is traced orad from the suture, so that its anterior limit cannot be located exactly. It has, however, become evident that there are some cephalopods in which the mural part of the septum terminates sharply some distance before the entire length of the camera wall is spanned. Thin sections indicate that this condition is common, and perhaps general, in the order Discosorida. The mural part of the septum is long, thick enough to be recognizable in many Actinoceratida and Endoceratida, and does extend essentially for the length of the camera wall. However, the condition is clearly variable in the Michelinoceratida. In that order there are many forms in which the mural part of the septum can be seen extending for the length of a whole camera, but there are some other forms of which this is certainly not true. The early Middle Devonian contains a number of orthocones with rather deep camerae, typified by *Michelinoceras tetricum* (Hall) of the Schoharie grit, in which the mural part of the septum may extend only two-thirds to three-fourths the distance forward from one septum to the next. Some specimens show a definite ridge at the anterior limit of the mural part of the septum in each camera.

Additional evidence of the structure of the mural part of the septum is supplied by the septal furrow (Flower, 1939) known in the earlier literature as the normal line. This was interpreted (Flower, 1939) as a middorsal structure developed where the mural part of the septum is wanting. Further confirmation of this interpretation is desirable; as yet it has not been substantiated by transverse thin sections of the shell. Such sections as have been made for this purpose show the mural part of the septum so thin, and so poorly differentiated from the shell wall as to be inconclusive. Whether this furrow is a zone where all or where part of the mural part of the septum is wanting, it certainly is inherent to the mural part of the septum. Where, as in *Michelinoceras tetricum*, the mural part of the septum does not extend for the whole length of the camera, the septal furrow is similarly confined. The belemnoids which show a septal line shortly anterior to the septum may show a septal furrow on the dorsum which extends for essentially the length of the camera. Thus if the interpretation of the septal furrow is correct, the septal line cannot possibly mark the anterior limit of an extremely short mural part of the septum, for the septal furrow indicates that the mural part of the septum occupies essentially the entire length of the camera.

The alternate suggestion, that the septal line marks the anterior limit of a very small cameral deposit, finds support in several specimens. In *Eobelemnites caneyensis* the septal line parallels the suture except at two points. It approaches the suture midventrally, and actually joins it middorsally. When viewed as a cameral deposit, this phenomenon is seen to parallel the pattern of cameral deposits noted in the Pseudorthoceratidae, the ventral lobe corresponding to the dorsal hiatus. Our present specimens of *Bactritimimus* fail to show such lobation, but none of the specimens preserve the middorsal region clearly, and the midventral region is complicated for other reasons, as will be seen.

In the holotype of *Bactritimimus girtyi* the area between the septum and the septal line is dark, polished, and contrasts strongly with the anterior lighter part of the cameral wall. It suggests that the darker color is due to a different substance than that comprising most of the filling of the camerae. In *Bactritimimus* cf. *B. ulrichi* some confirmation of this interpretation is seen. Here the material between the septum and the septal line is, for the most part, on a level with the remainder of the surface of the internal mold. Like the rest of this surface, it is smooth, almost polished in appearance. Further a faint longititudinal impressed line on the ventrolateral region continues over the entire cameral surface. However, there is a lateral region in which the material between the septum and the septal line has been removed, so that between these

structures there is a narrow concave zone. The surface of this zone is evenly curved and smooth, indicating that the surface thus exposed was a natural shell surface. Such a short rather thick band of material around the apical end of the wall of a camera is clearly consistent with the interpretation of the structure as a cameral deposit.

The septal line is of some importance in the present work because while it parallels the suture for the most part, it may deviate from the lobation of the suture in some significant details. In bactritids and some belemnoids the ventral part of the suture may appear as an incomplete structure, the septum terminating in apically pointing septal necks, and not continuous across the venter. In such cases the septal line may or may not show a lobation, and serves to supply some indication as to whether or not a true ventral lobe of the suture is really developed. Indeed, in his descriptions Shimansky (1954) has described the neck lobe as a ventral lobe in one part of a description, but in another has described, for the same species, a broader continuous lobe across the venter. This is in some cases the septal line, and in others a true continuous ventral lobe of a suture.

The Neck Lobe

In some bactritids and some belemnoids the suture is transverse across the venter, and in others it is definitely bent into a midventral lobe. Whichever condition occurs, there may be a modification of the septum in which it is bent strongly apicad ventrally, the apically pointing ends being free and not connected across the venter. Such a structure has sometimes been referred to as a ventral lobe. Since it may occur with or without a true ventral lobe, the terminology is misleading. For this structure the term neck lobe is proposed. More euphonious, perhaps, would be the term siphonal lobe, but this term has been applied to ventral lobes in cephalopods some of which are true ventral lobes while others are neck lobes, and perpetuation of this term would only extend the confusion further, Shimansky (1954) has not differentiated the neck lobe from a true ventral lobe, and as a result some confusion is encountered in reading his descriptions.

The development of the neck lobe appears, from our observations, to be a rather variable structure. It is not visible in the holotype of *Bactritimimus ulrichi*. It is slightly developed in the holotype of *B. girtyi*, but it is obscure there, because the cameral deposit shows a sharp apical boundary which simulates the true septum. In examining a suite of specimens of *Bactrites arkonensis* (Whiteaves) it was found that many specimens would show the neck lobe developed in some camerae but not in others. The variation appeared to be quite erratic throughout the length of a single specimen. Quite obviously, the presence of a neck lobe depends simply on the siphuncle being closely enough pressed against the ventral wall of the shell for it to show on an internal mold. The neck lobe is strongly developed in *Bactritimimus* cf. *ulrichi*, shown in Pl. 113, figs. 29–31. Fig. 31 is an enlargement presented to show the details of the structure. It will be noted that the apical septum shows a neck lobe, and directly orad of it the septal line indicates the development of a V-shaped ventral lobe. The next adoral suture shows the neck lobes equally well developed, but the septal line is not continuous across the midventral region.

In the material of *Bactrites arkonensis* already referred to there is also a septal line, but it is extremely close to the adapical septum ventrolaterally and ventrally, and joins it dorsally. On the venter of such specimens one may see in a few adjacent camerae (1) a normal suture, with septal line, and no neck lobe, (2) an incised neck lobe but with the suture and septal line continuous across the venter and (3) the neck lobe developed, open, with no suture continuous across the venter, but with the septal line still developed.

Descriptions of genera and species

Eobelemnites Flower 1945

Eobelemnites(?) sp.

Pl. 112, figs. 12–14

Under this designation is figures a specimen from the Chester of Alabama which appears to be a crushed phragmocone of a belemnite. The specimen is crushed obliquely laterally, increasing from 7 mm. high and 5 mm. wide to 14 mm. high and 11 mm. wide in 30 mm. It contains twelve camerae,

subequal in length, the first 1.8 mm. long, the last 2.1 mm. long. The sutures are sinuate, but the curvature shows no regard to the present symmetry of the shell, and some uncertainty attends any attempt to reconstruct the original pattern. It appears, however, that the phragmocone was very slightly curved originally, and that the sutures sloped forward on its concave side. There is no indication of the siphuncle, and the exposed ends of the specimen suggest that internal structures are largely destroyed.

Discussion.—The single specimen here described is so poor that its reference to any cephalopod genus is necessarily tentative. In the wide spacing of the septa, the obliquity of the sutures, slight curvature and rather rapid rate of expansion, it is unlike any nautiloid phragmocone so far known from the Mississippian of North America. The rate of expansion, spacing of septa and obliquity of sutures all recall *Eobelemnites caneyensis*, but details of proportion are sufficiently different that this form clearly must represent a distinct species. The form is too poorly preserved to merit a new specific name, but is worthy of note as the only indication thus far found of a belemnite in the Mississippian of Alabama.

Figured specimen.—Collection of R. H. Flower, New Mexico Bureau of Mines, Socorro, New Mexico.

Occurrence.—Collected by Mr. Frederick Mellen, who supplied the following data: "From chalky shale overlying the Hartselle sandstone and underlying the Bangor limestone, Chester group, from the NW¼, SE¼, sec. 31, T. 5 S., R. 10 W., Colbert County, Alabama." The same association contains the following species: "*Zaphrentis spinulosis*, *Pentremites* spp., *Orthotetes kaskaskiensis*, *Spirifer leidyi*, *Punctospirifer transversus*, *Capulus* (?) *sp.*"

PALEOCONUS Flower and Gordon, n. gen.
Genotype: *Paleoconus bakeri* Flower and Gordon, n. sp.

This belemnoid shell has a short blunt exogastrically curved rapidly expanding apex, beyond which the shell is straight and essentially tubular. The surface is smooth macroscopically, but under magnification shows numerous fine longitudinal obliquely imbricating raised lines of such low relief that great difficulty was encountered in photographing them. Extending forward from the apical cicatrix, which is remarkably similar to that of much younger belemnites, is a pair of deep lateral grooves which adorally assume a ventrolateral position. A pair of additional dorsolateral grooves appear midway between the apex and the region at which the apical curvature and rapid expansion of the rostrum are lost, and continue to the adoral end. Where the shell becomes straight and slender, there develops a rounded midventral ridge flanked by a pair of grooves. No middorsal ridges or furrows are evident, but the dorsum on our single specimen was probably slightly abraded.

The phragmocone is conical, moderately expanding in the adoral tubular part of the rostrum. It is circular in cross section, and adorally the rostrum is slightly thicker dorsally than ventrally. The surface of the phragmocone is not shown; conothecal markings are unknown. Septa are deeply curved, meeting dorsal and ventral walls at equivalent positions, suggesting straight transverse rather than oblique sutures. The siphuncle, close to the venter, has long sinuate septal necks, suggesting that the siphuncle segments expanded slightly within the cameriae. No cameral deposits are evident.

Discussion.—This genus is erected for the single species described below. It differs from *Eobelemnites* in that the phragmocone is circular and not compresssed in section, and the sutures are apparently straight and transverse. Features of the surface of the rostra of the two genera cannot be compared, since the rostral surface of *Eobelemnites* is yet unknown. In relation to *Eobelemnites caneyensis*, *P. bakeri* is a relatively tiny shell. There is no reason to believe that the phragmocone in *Paleoconus* extended any material distance orad of the rostrum, as did that of *Eobelemnites*.

PALEOCONUS BAKERI Flower and Gordon, n. sp.
Pl. 112, figs. 15–22

The unique holotype of this species is a portion of a belemnite 30 mm. long, containing the cicatrix at the tip of the rostrum apically, and extending forward to a point

at which the rostrum forms only a thin band around the anterior end of the phragmocone. The apex is blunt, with a lobed cicatrix 4 mm. across. The rostrum expands rapidly over the basal 10 mm., where it is exogastric, the dorsal profile slightly convex owing only to the adoral decrease in the rate of expansion, but the ventral profile much more strongly convex. The cross section is slightly compressed, 7.5 mm. wide, 8.5 mm. high. Beyond the initial 10 mm. the rostrum becomes tubular, the dorsum and venter straight and essentially parallel.

The broken adoral end of the specimen shows a circular phragmocone 6 mm. across, around which the rostrum forms a thin sheath, slightly thicker dorsally than ventrally.

The surface of the rostrum bears numerous fine narrow longitudinal imbricating raised lines which frequently form chevron-like patterns, on an otherwise smooth and polished surface. A pair of deep rounded grooves, their margins indistinct, extend forward laterally from the cicatrix, assuming a ventrolateral position in the later part of the shell. To these are added a pair of dorsolateral furrows which appear 8 mm. from the tip, and which extend to the adoral end of the specimen, becoming increasingly deep and prominent as they are traced adorally. They begin shortly before the termination of the apical rapidly expanded part of the rostrum. Slightly beyond, where the rostrum begins to assume a tubular form, a rounded median ventral ridge develops, flanked by two narrower grooves. Adorally there are traces of supplementary broad shallow ridges and grooves, none of which, however, approach those just described in prominence; indeed, they are so faint and shallow that their number and arrangement cannot be determined in detail.

The anterior part of the specimen was cut longitudinally, and the remaining part ground down to the siphuncle. The phragmocone was exposed for a length of 17 mm., in which its height increases from 2 to 6 mm. Only the septa at the base of this region are complete; they are deeply curved, the curvature equal to the length of a camera and one-fourth the height of the phragmocone at this point. Part of the siphuncle can be seen, but only in the adoral camerae where the septa are largely destroyed. It is narrowly separated from the venter; the septal necks are long, between a third and half the length of the camera, faintly sinuate in outline, suggesting that the entire siphuncle segment was slightly expanded in the camera. The section shows growth lines in the rostrum, longitudinal and parallel apically, but with their anterior parts curving centrad as they join the wall of the phragmocone.

The rostrum shows a fine black polished surface displaying the grooves, ridges and fine surface markings ventrally, over the left side and continuing onto the dorsum. The right side and part of the dorsum is rougher, and appears to have been slightly abraded prior to burial. Sectioning revealed that the specimen had been largely replaced by pyrite, and pyritization may be responsible for the destruction of the adoral septa of the phragmocone.

Holotype.—U. S. National Museum, no. 120021.

Occurrence.—Fayetteville shale, lower shale member, about 75 feet below base of Wedington sandstone member on south slope of Mt. Sequoyah (East Mountain) about 2 miles east of Fayetteville, Arkansas (USNM locality 3301).

HEMATITES Flower and Gordon, n. gen.
Genotype: *Hematites barbarae* Flower and Gordon

Rostra of this genus are very similar to those of *Aulacoceras* in general aspect, being variously pointed but essentially straight apically, tubular adorally, and with surface makings consisting of many fine longitudinal striae separated by flat raised interspaces. In the interspaces finer and less deeply incised transverse striae are evident. Furrows are present, and present a very different pattern from those of *Aulacoceras*. In that genus, and in the related *Dictyoconites*, the only prominent furrows are lateral, usually midlateral in the young and dorsolateral in later growth stages. In *Hematites* the furrows, some of which seem to be nothing more than more deeply incised striae, are generally concentrated on the ventral side of the shell. The genotype shows a midventral furrow which, is commonly the only one which is clearly evident from the very apex of the shell. A short distance anteriorly it is joined by a pair of

ventrolateral furrows, and still later, by a dorsal pair which are commonly fainter than the others. In later growth stages numerous accessory furrows may appear; spacing of the furrows and their number may be highly variable, and not always symmetrical. The other species included in the genus, *H. burbankensis*, lacks a midventral furrow in the adult, but there is reason to believe that this furrow is present in the young, and becomes suppressed in the adult. Both species show a constant concentration of the larger and stronger furrows on the ventral side of the shell.

The phragmocones of shells of this genus are moderately slender, faintly compressed in cross section, and show sutures which slope slightly forward from dorsum to venter but are straight, not sinuate. The siphuncle is commonly found definitely removed from the venter in the young, though closer to it in later growth stages. The septal necks are short, sinuate on the ventral side, sharply recurved dorsally. The connecting rings outline segments which are faintly sinuate in outline but essentially straight. Our present material suggests that the early part of the phragmocone was poorly calcified, and has failed to show a clear protoconch. The conothecal wall, as seen in sections is thin, and shows only such a faint suggestion of layering that it is impossible to recognize with certainty the three layers which Müller-Stoll (1936) has found in younger belemnoids.

In longitudinal section the rostrum shows a fibrous structure, but there is no clear axial element differentiated, and even growth lines are not clearly developed. In cross section the rostrum shows coarse radial units, similar to those known in *Aulacoceras* and *Dictyoconites*, but centrally around the phragmocone there develops irregular vesicular structure. The conothecal markings and the proostracum are unknown.

Discussion.—This genus is known from rostra, some of which enclose phragmocones in their adoral ends. At first it seemed that it would not be possible to distinguish this form from the Triassic *Aulacoceras*, which it resembles in the general aspect of the rostrum, but the absence of good lateral furrows and the concentration of furrows on the venter supplies a difference. Not much

---

EXPLANATION OF PLATE 112

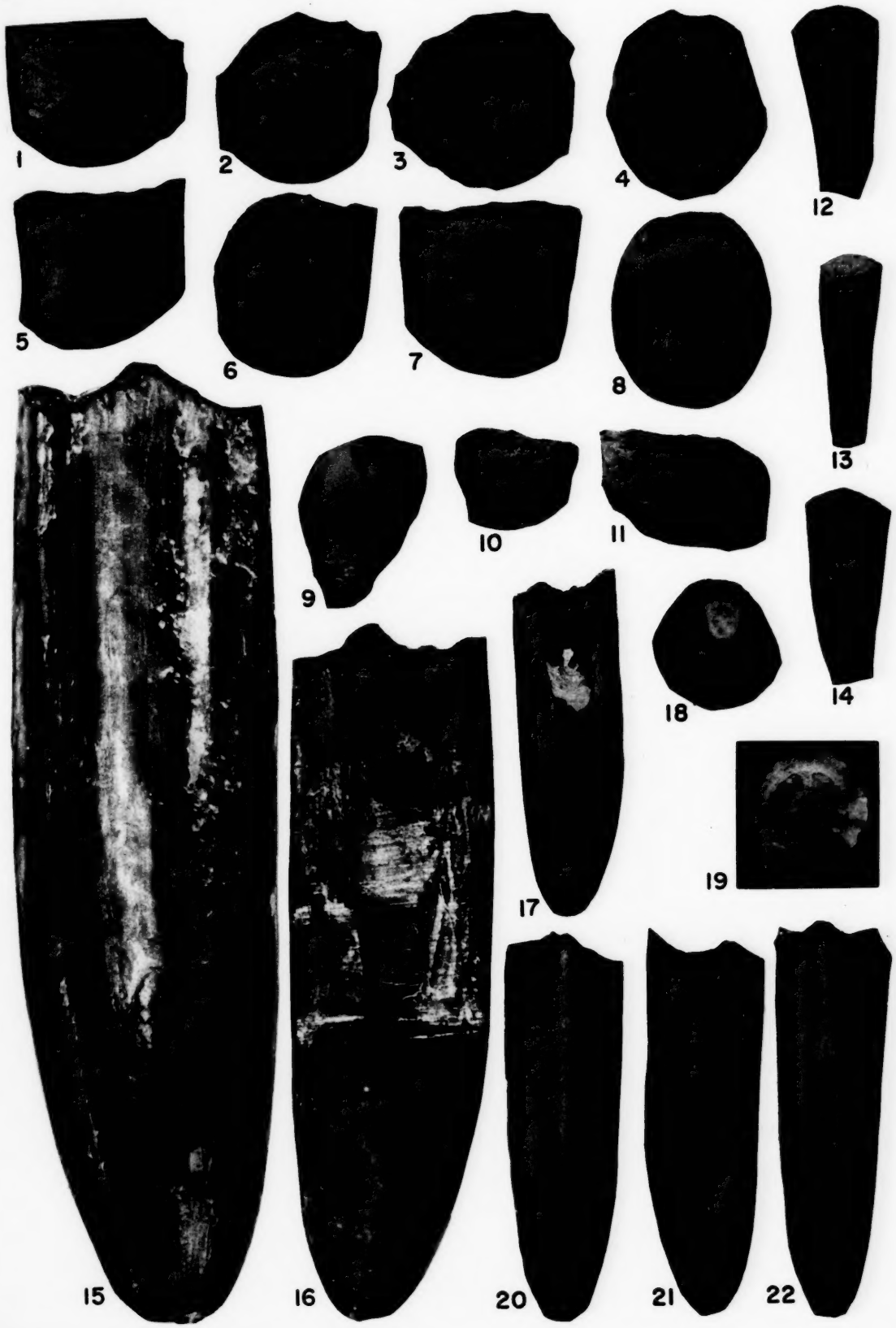
FIGS. *1–4*—*Bactritimimus ulrichi* Flower & Gordon. Four views of holotype, ×3.5. *1*, lateral view, venter on right, showing portion of rostrum. *2*, ventral view, showing siphuncle, narrow ventral lobe partly concealed by rostrum. *3*, lateral view, venter on left, showing course of sutures. *4*, septal view, venter below, showing siphuncle circular and narrowly separated from venter. USNM 119690, USGS loc. 1625. Fayetteville shale, near Marshall, Arkansas.

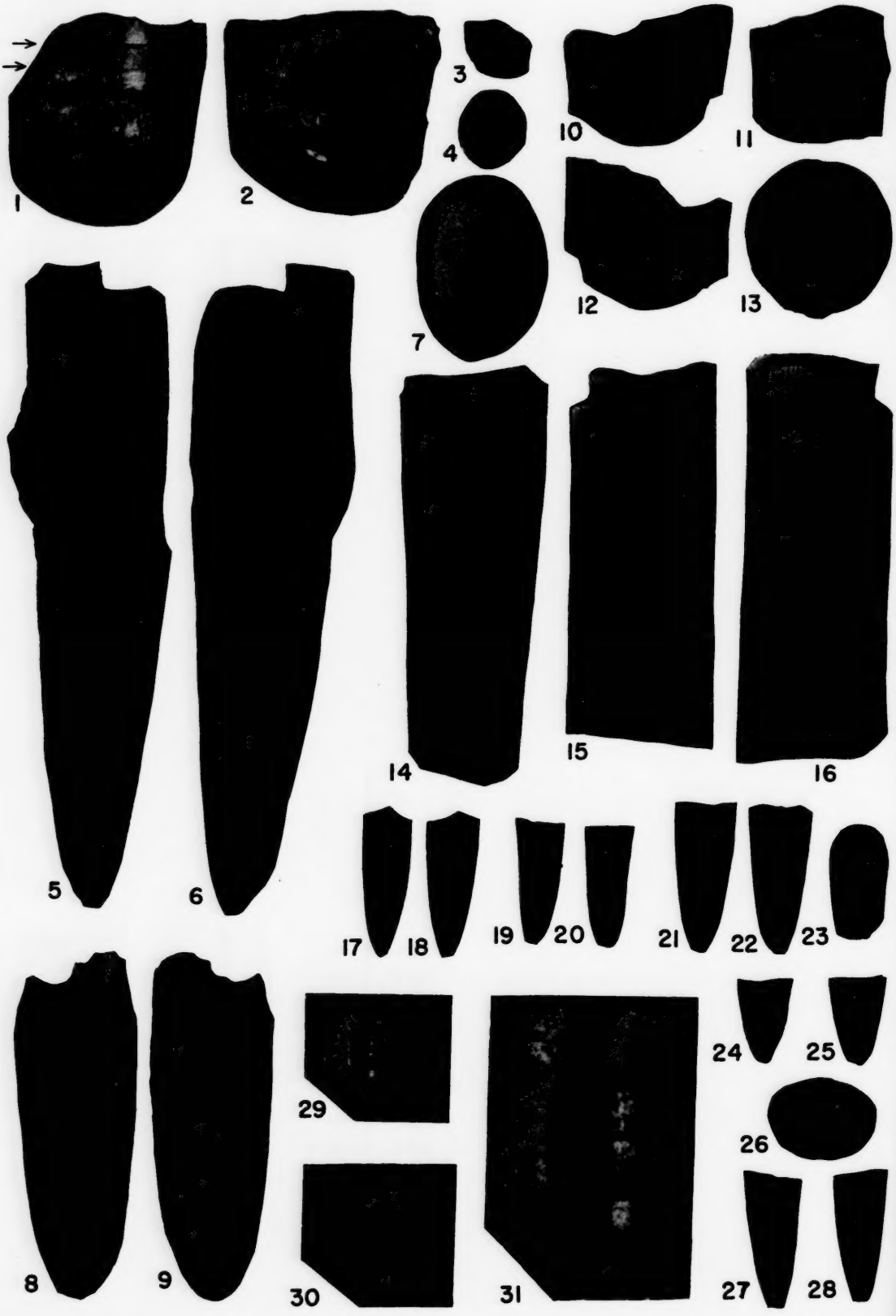
5–8—*Bactritimimus girtyi* Flower & Gordon. Four views of holotype, ×3.5. *5*, lateral view, venter on right. *6*, ventral view, showing broader ventral lobe and more prominent ventrolateral saddles than *B. ulrichi* in fig. 2. *7*, lateral view, venter on left, showing sinuous sutures. *8*, septal view, venter beneath, showing broadly rounded dorsum and siphuncle in flattened contact with venter. USNM 119689, USGS loc. 1619. Occurrence as in figs. 1–4.

9–11—*Bactritimimus* cf. *girtyi* Flower & Gordon. Three views of a fragment of phragmocone tentatively assigned to the species, ×3.5. *9*, septal view, venter beneath, midventral region and siphuncle wanting. *10*, ventral view. *11*, lateral view. USNM 120030, USGS loc. 1619. Occurrence as in the preceding specimens.

12–14—*Eobelemnites* (?) sp. Three views of a crushed phragmocone, ×1. *12* and *14* show opposite flattened sides, fig. *13* is viewed from the narrow slightly concave side, at left in fig. 12. Collection of R. H. Flower. From the Chester of Colbert County, Alabama.

15–22—*Paleoconus bakeri* Flower & Gordon. Views of the unique holotype. *15*, lateral view, venter on left, specimen photographed unwhitened, showing fine longitudinal markings of surface, ×5.5. *16*, lateral view, venter on right, anterior part of specimen sectioned showing pragmacone, and with portions of siphuncle preserved in extreme upper right, ×4. *17*, same view, ×2, at an earlier stage of grinding, not attaining center of phragmocone, but showing curved growth lines of anterior part of rostrum. *18*, apical view, venter beneath, ×3. *19*, adoral view of specimen prior to sectioning, showing circular phragmocone with rostrum surrounding it slightly thicker dorsally than ventrally, ×2.4. *20*, ventral view, showing furrow flanked by grooves. *21*, lateral view, venter on left. *22*, dorsal view, showing faint dorsolateral furrows, all ×2.4, from whitened specimen prior to sectioning. USNM 120021, USNM loc. 3301.


1
2
3
4
12
5
6
7
8
13
9
10
11
14
18
19
17
15
16
20
21
22


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31

attention has been given in the literature to the phragmocone of *Aulacoceras*, but its phragmocone is commonly compressed. Slight obliquity of the sutures is not evident. von Bülow (1915) illustrates for *Aulococeras* a tiny subspherical protoconch, but one hardly larger than the adjacent part of the phragmocone. Siphuncles have not been described or figured in any detail. The illustration of von Bülow (1915, Pl. 58, fig. 6), suggests a tubular siphuncle essentially in contact with the venter, but does not show the condition of the septal necks. However, quite similar necks have been figured for *Ausseites sulcatum* (Hauer) and *A. alvelolaris* (Quenstedt) by Mojsisovics (1873–1902, Supp. Pls. 13, 15).

Close comparison with *Eobelemnites* is difficult, for neither the surface nor the tip of the rostrum is known in that genus. However, the radial fibres of that genus in the rostrum seem finer and contain less organic matter, the general effect being one of prisms of aragonite and in general a more solid and less fibrous structure. The phragmocone of *Eobelemnites* is quite unlike that of *Hematites*, being strongly compressed in section, quite rapidly expanding, having sutures which slope strongly forward from venter to dorsum, and its siphuncle has relatively long septal necks.

Paleoconus is readily differentiated by the relatively smooth rostral surface, the very different pattern of the broad rounded furrows, and its slightly exogastric tip. Its phragmocone is circular in section, its

---

EXPLANATION OF PLATE 113

FIGS. *1,2—Bactritimimus girtyi* Flower & Gordon, two views of holotype ×4, photographed unwhitened to show surface texture and color. *1*, ventral view, showing ventral lobes without development of neck lobes, dull zone between septum (upper arrow) and septal line (lower arrow); and polished dark zone below. *2*, lateral view, venter on left, showing polished septal surface and dark band between septal line and septum (suture).

3,4,8,9—Hematites barbarae Flower & Gordon. Two specimens from the Fayetteville shale near Marshall, Arkansas, USNM 118997, USGS loc. 14363. *3*, lateral view and *4*, septal view of small fragment of phragmocone with a septum at the base, the wall surrounded by rostral material, ×2. *8,9*. A weathered rostrum, ×2.2. *8*, dorsal view, showing dorsal furrows below, conothecal cavity above. *9*, opposite side, midventral furrow slightly to right of center; ventrolateral furrows very faint.

5–7—Hematites barbarae Flower & Gordon. A paratype from the Fayetteville shale near Fayetteville, Arkansas, ×2.2. USNM 118996, USNM loc. 3301. *5*, dorsal side, with two dorsal furrows and a fainter third one below, matrix in the flattened conotheca above. *6*, opposite side, showing prominent midventral furrow and pair of ventrolateral furrows.

10–16—Hematites barbarae Flower & Gordon. Holotype, two pieces believed to be parts of the same specimen, but with one camera missing between them, ×2. USNM 120022A and B, USGS loc. 17187. *10*, dorsal view of adoral fragment, showing very broad lobes. *11*, lateral view, venter at right. *12*, ventral view. *13*, septal view, venter beneath, showing small circular septal foramen. *14*, lateral view of adapical portion, venter on right. *15*, dorsal view, and *16*, ventral view, showing midventral and two ventrolateral strong furrows.

17–28—Hematites barbarae, five paratypes showing variation of shape among forms with relatively acicular apices, USNM 120024I-M, USGS loc. 15165. *17* and *18*, USNM 120024M, ventral and dorsal views of an apical fragment, an immature individual, showing numerous furrows on the ventral side developed relatively close to apex. *19* and *20*, USNM 120024L two views of an obliquely flattened fragment, with midventral furrow to left of fig. 19, and with apparent slight endogastric curvature, all ×1. *21–23*, USNM 1200241, another fragment, with more prominent striae. *21*, dorsal view, with dorsolateral furrows evident. *22*, ventral view, with midventral furrow clear to apex and ventrolateral furrows less extended apically, ×1. *23*, apical view, ×2. *24,25*, USNM 120024K, a specimen showing a small strongly flattened apex. *24*, ventral view showing clear midventral furrow. *25*, dorsal view. *26–28*, USNM 120024J, a specimen with less acute apex. *26*, apical view, ×2. *27*, one flattened side, midventral furrow slightly to left of center. *28*, opposite side, showing very faint dorsal furrows.

29–31—Bactritimimus cf. *ulrichi* Flower & Gordon. A fragmentary specimen agreeing with *B. ulrichi* in general proportions, but with more rounded ventrolateral lobes. *29*, ventrolateral view ×2.5, photographed unwhitened, showing neck lobes. *30*, same view specimen whitened, ×3. *31*, enlargement ×5 of ventral portion, showing detail of neck lobes and septal line. USNM 120029, USGS loc. 1619, Fayetteville shale near Marshall, Arkansas.

sutures essentially straight and transverse, its siphuncle slightly removed from the venter and with long faintly sinuate necks essentially parallel to the axis of the siphuncle. Though the original condition of the rostrum is altered in the one known specimen, it appears to be texturally more akin to *Eobelemnites* than to *Hematites* or *Aulacoceras*.

HEMATITES BARBARAE Flower and Gordon, n. sp.
Pl. 113, figs. 3–28; Pl. 114,; Pl. 115, figs. 13–15,18–22; Pl. 116

This species is represented by 252 fragmentary specimens from the Chainman shale of Utah and three specimens from the Fayetteville shale of Arkansas.

The apex is variable, acicular to very bluntly pointed, rarely rounded or truncated. The rostrum is gently enlarging initially, essentially parallel-sided adorally, originally circular in cross section, but most known specimens are somewhat crushed. The rostral surface bears numerous fine longitudinal striae; the spaces between are flat and are crossed by finer rather irregular transverse striae which cannot be traced across the longitudinal ones. Furrows are extremely variable, but in general a midventral furrow is clear throughout the length and usually prominent, and is flanked by a ventrolateral pair of furrows, not ordinarily traceable clearly to the apex, and a dorsal pair, usually fainter than the others and not appearing until after the initial more rapidly expanding apical part of the shell is passed. Supplementary furrows develop in later growth stages, and show wide variation in number and spacing, producing patterns which are, in many examples, quite asymmetrical.

Phragmocones are known only from portions enclosed by the rostra. Generally such specimens show a crushing of the shell which becomes progressively greater as it is traced adorally, obviously because the rostrum thins adorally and its strength diminishes proportionately. Phragmocones are slightly compressed in section, the sutures slope very slightly forward from dorsum to venter, but are not lobed or sinute. The siphuncle, as seen from sections, is some distance from the venter in the young, enough so that one would not expect the internal mold of the phragmocone to show a neck lobe; however, in the latest growth stage of the phragmocone observed (Pl. 113, figs. 10–13), the siphuncle is essentially in contact with the ventral wall of the shell, though no neck lobe is apparent on the surface of the internal mold.

The numerous fragmentary rostra by which this species is represented in the Chainman shale show such wide variation in form of apex, general character of the fine striae of the surface, and in the number, arrangement and prominence of the furrows, that much time was consumed in a study to determine whether they might not represent several distinct species. Except for the differentiation of *H. burbankensis*, in which the midventral furrow is suppressed, it has been concluded that the material represents a single variable species. The illustrated specimens have been selected to show the character of this variation, and are discussed individually below. So wide is the variation, shown by the suite of specimens from the Chainman shale of the Burbank Hills, that the species defined on this material must, morphologically, embrace the three shells from the Fayetteville shale of Arkansas.

Holotype.—Two fragments, the only specimens which show an undistorted phragmocone are regarded as representing two parts of a single individual, though they do not actually fit together. Destruction of one or at the most two camerae between these portions will account for the discrepancy. The one, USNM 120022B, shown on Pl. 113, figs. 13–16, is the earlier part of a rostrum, 32 mm. long. Its apical end is somewhat crushed vertically, and the broken end shows only rostral material here with no trace of the conotheca. It is 12 mm. wide and 8 mm. high. The anterior end is uncrushed, and shows the rostrum circular, 12.6 mm. in diameter, enclosing a phragmocone which is 11 mm. high, 10 mm. wide, compressed, its sides very slightly flattened, its dorsum and venter equally rounded. The siphuncle is circular in section, 0.9 mm. in diameter, and is very narrowly separated from the venter. The rostrum shows on its ventral side a very deep midventral furrow.

On either side are two prominent ventrolateral furrows, that on the right supplemented by a second deep furrow between it and the ventral one. On the dorsum the pair of dorsolateral furrows is visible but faint, and difficult to distinguish from additional very fine longitudinal striae. Preservation of the surface details is rather poor, and the fine transverse striae crossing interspaces cannot be made out.

The other fragment, USNM 120022A, believed to represent a part of the same specimen, is shown on Pl. 113 figs. 10–12. It is part of a phragmocone 12 mm. long comprising four camerae, and retaining fragments of the rostrum. The camerae average 2 mm. in depth, four occurring in 8 mm. on the venter. The sutures slope only very faintly forward from dorsum to venter, and are straight with no trace of sinuosity. The phragmocone increases in width from 10.5 mm. to 12 mm. The height is 11 mm. at the base, incomplete adorally, estimated at 12.5 mm. The septum at the base is slightly more deeply curved dorsally than ventrally, 2 mm. deep, where height and width are 11 mm. and 10.5 mm. respectively. The siphuncle as before, is small, circular and only most narrowly separated from the ventral wall of the phragmocone. The fragmentary rostrum agrees in its surface features with the preceding specimen. In cross section the rostrum is noticeably thicker at the sides of the phragmocone than elsewhere, and is very slightly thicker ventrally than dorsally.

Utah paratypes.—USNM 120023A, Pl. 114, figs. 22,23, shows one of the longest rostral fragments, 75 mm. long. The tip is square cut and without clear surface markings. The sides diverge moderately apically, attaining 9 and 11 mm. in diamters 27 mm. from the tip, and then increasing to only 11 and 13 mm. 10 mm. from the anterior end, the extreme anterior part showing progressive flattening, and showing the rostrum thinning anteriorly around the conotheca. The rostrum bears a prominent midventral furrow, the ventrolateral pair is not prominent, but the dorsal pair is well differentiated in the adoral three-fourths of the specimen. As in the holotype, fine surface details are rather poorly preserved.

USNM 120024C, on Pl. 114, figs. 24,25, is figured a fragment with rather deep longitudinal striae. This is a rostrum 45 mm. long, the anterior end strongly flattened, 15 mm. wide, 5 mm. high, where the rostrum is about 1 mm. thick around the conotheca. The venter can be identified by the midventral furrow, deep and strong apically, but fainter adorally where the ventrolateral pair of furrows, which are faint apically, come to exceed the ventral one in prominence. On the opposite side crushing has distorted the dorsum, so that one of the dorsolateral pair of furrows is prominent, the other obscure.

USNM 120024D, on Pl. 115, figs. 18,19, shows a quite different type of surface marking, in which the striae are fainter and somewhat more closely spaced. This is a rostrum 50 mm. long, with the usual progressive adoral flattening over the anterior part, which encloses the conotheca. This shell is flattened laterally, and though the tip is essentially symmetrical, the middle part of the rostrum shows a very slight exogastric curvature. The ventral furrow, seen at the extreme right of Pl. 115, fig. 18, is flanked closely by a pair of slightly shallower furrows which become obscure when traced apically. The prominent ventrolateral furrows are well developed. On the dorsum there are four subequal rather shallow furrows all of which extend rather closer to the apex than is usual.

One specimen, USNM 120024B, Pl. 114, figs. 18,19, is unusual in having the surface relatively smooth, the incised longitudinal lines being faint and shallow, while the transverse striae are not similarly reduced, resulting in a reticular or faintly beaded appearance of the surface. The specimen is a fragment 31 mm. long, showing a moderately pointed apex, increasing to 11 and 10 mm. adorally, the adoral end enclosing a phragmocone of about half its diameter at this point. Of the furrows, all are faint, but the ventral and ventrolateral furrows can be differentiated on one side, and the dorsal pair is recognizable on the other.

Another specimen, USNM 120024H, Pl. 114, figs. 15–17, extends for a length of 27 mm. attaining in 22 mm. measurements of 9 and 11 mm. This rostrum is slightly compressed, the tip blunt, faintly exogastrically curved, and resembling the tip of *Paleoconus*

in this respect. The surface is covered with rather coarse, irregular imbricating longitudinal markings, and is devoid of any of the furrows seen in the other specimens. A callosity at mid-length produces an irregularity of form suggestive of injury or disease, and the specimen is regarded as an abnormal one for this reason. Were this not true, the differences would be such that they would merit serious consideration as a basis for separating this specimen as a distinct species.

One specimen, USNM 120024A, Pl. 114 figs. 20,21, shows five clear furrows on the ventral side, but they are quite uneven in their spacing and the central three can be traced essentially to the apex. The opposite side shows only a rather fainter pair of dorsal furrows. This is a rather strongly flattened rostrum 45 mm. long, attaining a flattened width of 12 mm. Anteriorly the rostrum is only 0.8 mm. thick around the conothecal cavity.

Another paratype. USNM 120023D, shown on Pl. 115 figs. 20–22, is a rostrum 49 mm. long, progressively flattened adorally and the rostral material 3 mm. thick at the anterior end around the conothecal cavity. Striae of the surface are fine and numerous, those on the dorsal side near the apex fine and with the interspaces prominently flattened; on the ventral side the striae are deeper apically and the flattening of the interspaces is less conspicuous. On the venter a midventral furrow can be traced throughout the length of the specimen. A pair of ventrolateral furrows is prominently developed, both fading out in the apical 5 mm., and the one to the left farther from the midventral furrow adorally than the one on the right. Between the left ventrolateral furrow and the midventral one a secondary furrow appears which becomes quite prominent adorally, but is without a counterpart on the opposite side. Dorsally the usual pair of dorsal furrows is not clearly developed. They are faintly indicated, but do not extend close to the apex, and adorally the dorsum is rather poorly preserved. Two pairs of faint lateral furrows are developed, and laterally the fine striae are oblique, particularly in the apical third of the specimen, suggesting the "asymptodic markings" of the lateral portion near the tip of the rostrum of *Aulacoceras* figured by von Bülow (1915).

Wide variation in the form of the apex is shown by the suite of specimens. Five specimens, USMN 120024I–M, selected for showing variations in the more slender more pointed apices are figured in Pl. 113, figs. 17–28. Pl. 113, fig. 17, USNM 120024M, shows the ventral side of a small apex, a short rostrum which is considerably flattened, and shows at its anterior flattened end a conotheca around which the rostrum is only about 1 mm. thick. Four prominent grooves are apparent in this view, and a fifth lies on the right margin of the specimen. The opposite side shows two dorsal furrows, and the middorsal region is here to the right of the center. The specimen is 14 mm. long, and attains an adoral flattened width of 9 mm. with a height of 4 mm. A second specimen, USNM 120024L, shown on Pl. 113, figs. 19,20, is 19 mm. long, evidently compressed by flattening, 8 mm. high and 6 mm. wide at the adoral end. The ventral side, marked by prominent furrows, is evidently to the right of Pl. 113, fig. 19, which shows one prominent furrow, the midventral one, close to the left, while nearer the center the one ventrolateral furrow is supplemented by another close to it. The ventrolateral furrow on the other side of the midventral one is marginal and not shown in this view. The opposite side of the specimen, Pl. 113, fig. 20, shows the dorsal pair of furrows rather faint at the right of the center.

A third specimen, USNM 120024I, Pl. 113, figs. 21–23, shows a slightly more rapidly expanding apex than figs. 17,18, though adoral compression of the specimen is somewhat less. The fragment is 24 mm. long, increasing to 7 and 10 mm. adorally. The ventral side (fig. 22) shows one prominent midventral furrow strong to the tip, slightly to the right of the center, flanked rather closely by a ventrolateral pair. The opposite side shows a pair of dorsal furrows, rather faint because the finer striae are rather deeply incised. Some secondary lateral furrows are developed, variable in strength and spacing on the two sides. The apex is typical in appearance.

USNM 120024K, on Pl. 113, figs. 24,25, shows a small strongly flattened apex, a

fragment 14 mm. long, measuring 9 and 4 mm. adorally. On the venter, fig. 24, there is a clear midventral furrow; ventrolateral furrows are rather widely spaced and somewhat weaker. Dorsally there appear to be three dorsal furrows, but this appearance is probably the result of crushing.

USNM 120024J, on Pl. 113, figs. 26–28, represents a fragment 22 mm. long, 7 and 10 mm. adorally, in which the fine markings are rather shallow. Pl. 113, fig. 27 shows one flattened side with two prominent furrows; two very closely spaced furrows occur on the left lateral side of the same figure. The opposite side shows three rather widely spaced shallower furrows. This is one of the specimens from which orientation of the shell is rather uncertain, but it appears that here the furrow to the left of the midventer is supplemented by a secondary one, though both penetrate quite close to the apex.

Some forms, not otherwise distinguishable, have short blunt rapidly expanding apices which, together, form a series resembling closely the successive stages of the apex connected with loss of the epirostrum and subsequent modifications of the tip of the rostrum. Yet in spite of careful search, nothing in our material could be identified as a true epirostrum. This is not surprising; indeed, were so remarkable a structure as the epirostrum developed in Mississippian belemnites it would be most remarkable. However, it is significant that these variations of the apex can occur without evidence of a true epirostrum.

USNM 120023C, on Pl. 115, figs. 13–15, is a large portion of a belemnite, with a rather bluntly pointed rostrum, its tip typical, pointed, the sides slightly convex over an unusually long distance. The specimen is 48 mm. long, the sides slightly convex for about two-thirds of that length, the anterior end slightly flattened, 14 by 10 mm., and enclosing a phragmocone of about half that size, showing the position of the siphuncle. The one flattened side, shown on Pl. 115, fig. 15, shows three prominent furrows: two more are around on the left side. The one here visible on the left is apparently the midventral furrow. The siphuncle is not aligned with it perfectly, but the phragmocone is considerably distorted by flattening. The opposite side shows finer closer striae, among which the dorsal pair of furrows is obscure. One, at the center of the specimen as seen in this view, is accentuated by crushing, but its mate is obscure.

USNM 120024E, on Pl. 114, figs. 11–14, shows a specimen rather unusual in form and apex. This has at its apex a large button-like blunt cicatrix, orad of which there is an irregular constriction of the rostrum, almost as though it were etched there. The materials described thus far occupy only the apical 4 mm. of the specimen, and the rostrum has attained a diameter of 8 mm. In the remaining length of 28 mm. the rostrum increases to 10 and 9.5 mm. Striae on the surface of this form are very shallow and faintly incised, resembling the specimen shown on Pl. 114, figs. 18,19, USNM 120024B. A prominent midventral furrow and a prominent pair of ventrolateral furrows are developed, but others are extremely faint and the dorsal pair cannot be distinguished with certainty.

USNM 120024G, on Pl. 114, figs. 1–4, shows another form with a blunt tip. This is a fragment 24 mm. long, 8 and 12 mm. across adorally. The tip is very bluntly rounded, a little irregular. The dorsal side shows the dorsal pair of furrows strongly developed, and centered a little to the right of the center. The opposite side shows a number of furrows, the midventral one the strongest, and lying a little to the right of the center.

USNM 120024F, on Pl. 114, figs. 5–8, shows another type of apex, this represented only by the single specimen here figured. This is a fragment 22 mm. long, the apical 5 mm. slender, strongly striate, then expanding abruptly to 8 and 9 mm. and continuing for 19 mm. to 10 and 11 mm. Striae are coarse, irregular somewhat anastomosing. The midventral furrow and ventrolateral furrows are prominent, centered a little askew on the one flattened side. The opposite side shows the pair of dorsal furrows, the one on the left obscure apically and altogether somewhat fainter than the one on the right.

Arkansas paratypes.—Two specimens from the Fayetteville shale of Arkansas fall within the morphological limits of this rather variable species. One specimen, USNM 118997, from USGS locality 14363, shown on Pl. 113, figs. 8,9, consists of a

rostrum showing an alveolus in its weathered anterior end. The specimen is slender, straight, the outline of the rostrum slightly convex in the basal 10 mm. and thereafter essentially parallel sided. The apex shows a small rather obscure cicatrix 0.8 mm. across. The shell attains dimensions of 7 and 8.5 mm. 10 mm. from the apex, increasing to only 8 and 9.5 mm. 18 mm. from the apex, the farthest point forward at which both greater and lesser diameters are retained, although the rostrum partially enclosing an alveolar cavity extends 9 mm. farther forward.

Grooves on the rostrum are a little difficult to interpret, but the more complete side shows two prominent grooves, of which the one to the right represents the midventral one, that on the left one of the ventrolateral grooves, while the other ventrolateral groove, farther to the right, is obscured by weathering. The opposite side has the apical end weathered, but the anterior surface of the rostrum shows a pair of grooves typical of the dorsal grooves of the Utah material.

The alveolar cavity is somewhat less strongly depressed than is the rostrum around it; with the rostrum restored to its apparently originally circular cross section, the alveolus would be slightly compressed in cross section. At present this alveolus is filled with matrix, shows no trace of septa or siphuncle, and is consequently no guide to orientation of the specimen.

The surface bears numerous fine imbricating markings somewhat coarser in texture where weathering has penetrated beneath the surface of the rostrum.

A small fragment from the same locality was unfortunately lost, but was photographed first and is shown on Pl. 115, figs. 3,4. This showed a septal surface. The septum is very slightly arched and shows a small ventral septal foramen. A section normal to the septal surface is very slightly compressed, and the suture slopes slightly forward from dorsum to venter. Measurements normal to the section of the rostrum, rather than to the septum, would indicate the cross section of the phragmocone to be essentially circular.

This specimen had a septum 4 mm. wide, 5 mm. high and extended 3 mm. orad of the septum, showing on its sides part of the rostrum.

A third specimen, USNM 118996, also from the Fayetteville shale, USNM locality 3301, shown on Pl. 113, figs. 5–7, differs somewhat from the preceding one, though both lie within the wide limits of variation exhibited by the Chainman shale specimens. This shell is 50 mm. long, showing flattening which becomes progressively greater adorally. In the adoral 22 mm. the dorsum is missing, and the exposed interior shows an alveolar cavity, probably originally a phragmocone, but with septa destroyed, and the rostrum thinning around it from 2 mm. to less than 0.5 mm. at the extreme anterior end.

The rostrum is somewhat more acute apically than in the preceding specimen, the cicatrix 0.8 mm. across, the shell expanding in the apical 10 mm. to a height of 7 mm. and a width of 8 mm. Beyond this point the increase in size is much less marked; 28 mm. from the apex the shell is 8 mm. high and 12 mm. wide and at the anterior end its width is not quite complete, but is estimated at 14 mm.

The surface is covered with fine longitudinal striae, anastomosing in places. Apically three to four striae occur in a width of 1 mm. and adorally five to six occur in the same width. The longitudinal furrows on the shell include one prominent midventral furrow nearly at the center of the flattened surface shown on Pl. 113, fig. 6, and three closely spaced lateral furrows, at each side of the venter visible in the same figures. Of these the central one of the three appars to be primary, and extends close to the tip of the rostrum. On the opposite side a pair of dorsal furrows occurs, but they cannot be traced very close to the apex, and at the adoral end of the rostal surface a third furrow appears rather asymmetrically placed between them.

This specimen shows one apparent difference from the others which, in view of crushing of the shell may not be real, namely, an apparently much more slender and longer alveolus or phragmocone.

Internal structure.—A number of specimens, USNM 120025A–E, of *H. barbarae* were used as the basis of a series of thin sections. Though much of the material proved

unsatisfactory, and much more was weathered, porous, somewhat friable and difficult to handle, a number of sections were obtained. Several of these, illustrated on Pl. 116, show some unusual features.

The rostrum shows in longitudinal section (Pl. 116, fig. 1, USNM 120025A) numerous longitudinal fibres with closer transverse dark fibrous material betweeen them. It may be noted that growth lines, showing earlier positions of the outline of the apex, are developed, but only most obscurely. Though great care was taken that the section should penetrate the center of the rostrum, no differentiation of axial material can be found. A cross section (Pl. 116, fig. 3, USNM 120025C) of a rostrum with the apical part of the phragmocone at its center. shows surrounding the phragmocone a zone of rather irregular vesicular material, but near the outside rather coarse radial markings. It is not altogether clear whether, as the section suggests, there is an abundance of dark organic material on the outside which penetrates as radial lines toward the center, or whether the dark material is of inorganic origin, a staining which failed to penetrate to the center. The central vesicular part of the rostrum shown in this section is amazingly suggestive of the epirostrum which Müller-Stoll has figured for younger belemnoids. However, the development of an epirostrum around the phragmocone is completely inconsistent with all that is known or believed concerning that remarkable structure.

Several sections of the phragmocone, conotheca and surrounding rostral materials agree in general features. In general, the rostral material around the phragmocone shows prominent longitudinal elements and finer secondary transverse ones. Only one section (Pl. 116, fig. 2, USNM 120025B) shows any suggestion of anterior growth lines of a rostrum which slope centrad adorally. These lines are straight, not curved as in *Paleoconus* (Pl. 112, fig. 17). The conotheca is thin and the sections so far made fail to show clearly the three layers which Müller-Stoll has found in younger belemnoids, and which have come to be regarded as generally characteristic of the whole belemnoid line. The septa are moderately spaced, moderately curved, and the siphuncle is slightly removed from the venter. Various sections have indicated some variation in the form of the septal necks, an effect which is partly at least the result of vicissitudes of preservation. However, siphuncles with some segments complete are shown on Pl. 116, figs. 2 and 7. Fig. 6 on the same plate shows a portion of the dorsal side of the siphuncle, with the short strongly recurved septal neck there which has been noted in the description of the genus.

A remarkable and most unexpected feature of this material has been its failure to disclose anything which could be called a protoconch. Pl. 116, fig. 5, USNM 120025E, shows a sagittal section through a phragmocone, the siphuncle on the ventral side at the right. The specimen is crushed, but parts of four septa are visible in the figure, and three and a half siphuncle segments, in which the connecting rings are largely destroyed. The apex of the phragmocone is crushed, but the amazing feature is that there seems to be an abrupt apical termination of the conotheca, and no allowance for crushing, can by itself account for the destruction of an orginal protoconch. A second section (Pl. 116, fig. 2) attains close to the apex of the phragmocone. In the apical part of this specimen the septa are wanting and the wall of the conotheca, well defined anteriorly, becomes vague apically as though it was a structure which was calcified only most poorly if at all. A similar section in Pl. 116, fig. 4, USNM 120025D, is of uncertain orientation, but shows the apex of a phragmocone enclosed by a rostrum in which, again all parts of the phragmocone appear to be poorly calcified, and no protoconch is apparent.

Holotype.—USNM 120022A,B (USGS loc. 17187).

Paratypes.—USNM 118996 (USNM loc. 3301), 118997 (USGS loc. 14363), 120023A–D (USGS loc. 17187), 120024A–M (USGS loc. 15165), 120025A–E (USGS loc. 15165, slides).

Occurrence.—Chainman shale, middle part, USGS localities 15165 (paratypes), 15166. 17055, 17186, 17187 (holotype and paratypes), 17194, Burbank Hills; 15157, Needle Range; Millard County, Utah. Fayetteville shale, lower part, USNM local-

ity 3301 (paratype), 2 miles east of Fayetteville, Washington County; USGS locality 14363 (paratypes), Marshall, Searcy County; Arkansas.

HEMATITES BURBANKENSIS Flower and Gordon, n. sp.
Pl. 115, figs. 1–12,16,17

Among the abundant material of *Hematites* from the Burbank Hills there are a few specimens which differ from *H. barbarae* in that there is clearly no midventral furrow, but instead a pair of furrows flanking the venter rather closely, outside of which the usual ventrolateral pair of furrows is developed. This condition is evident in three specimens, all fragments failing to retain the apex of the rostrum, but clearly oriented by the position of the siphuncle in the phragmocone.

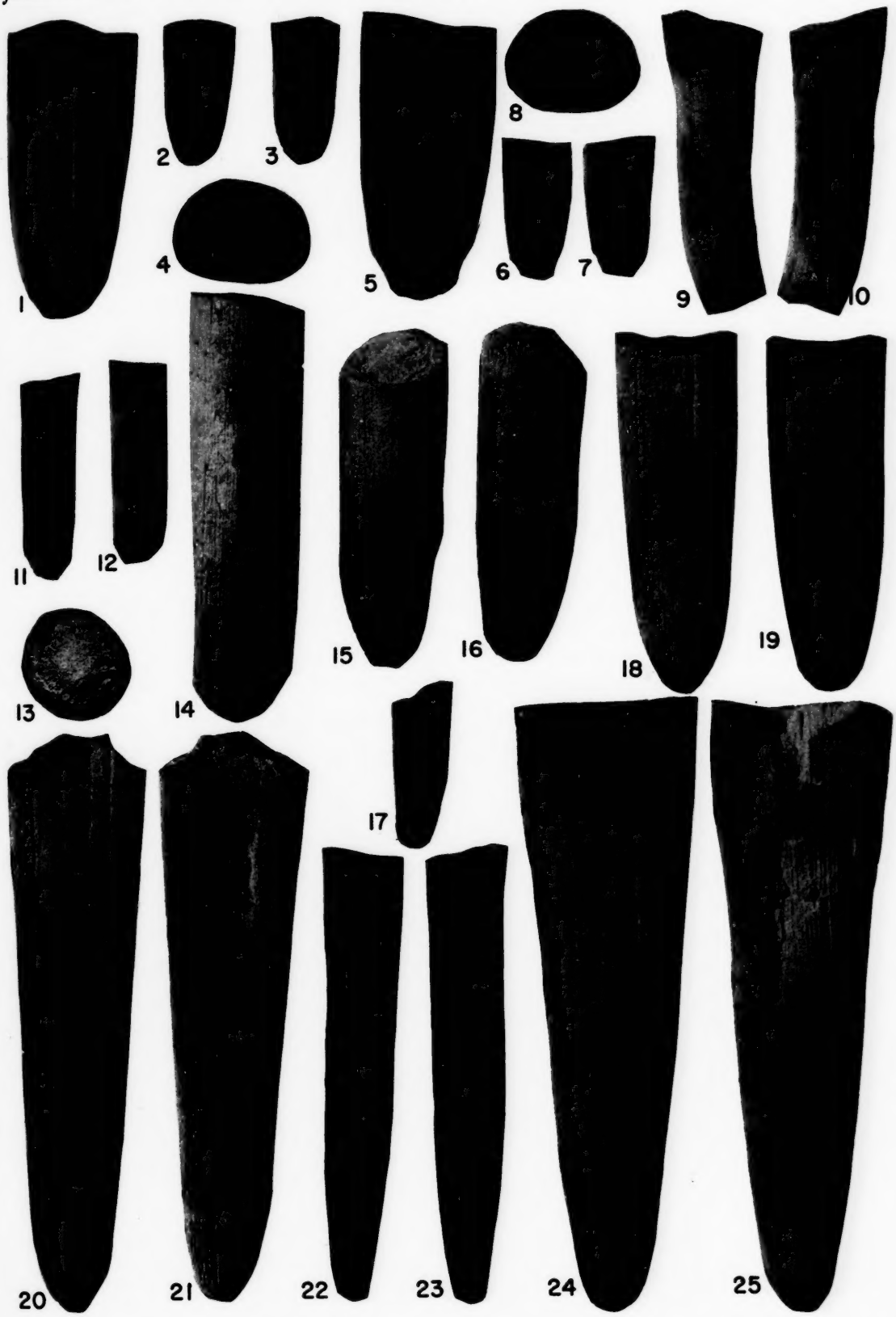
The holotype, USNM 120026, Pl. 115, figs. 1–4, is a fragment of a rostrum 25 mm. long. The apical end is strongly flattened, and the break at its end shows only rostral material. It is 10 mm. wide and 4.5 mm. high. At the adoral end the rostrum is 11 mm. wide and 7 mm. high, showing a section through a phragmocone 6 mm. wide and 3.5 mm. high. Flattening is vertical, and the siphuncle is clearly visible. The siphuncle is aligned perfectly between a pair of prominent ventral furrows, outside of which a second pair occurs, slightly uneven in spacing, the two furrows on the left being slightly closer than those on the right. Fine striae on the surface are faint and obscure, possibly due to wear of the fragment prior to burial. On the dorsum a faint dorsal pair of furrows can be recognized, but they are not much stronger than some of the stronger of the longitudinal striae.

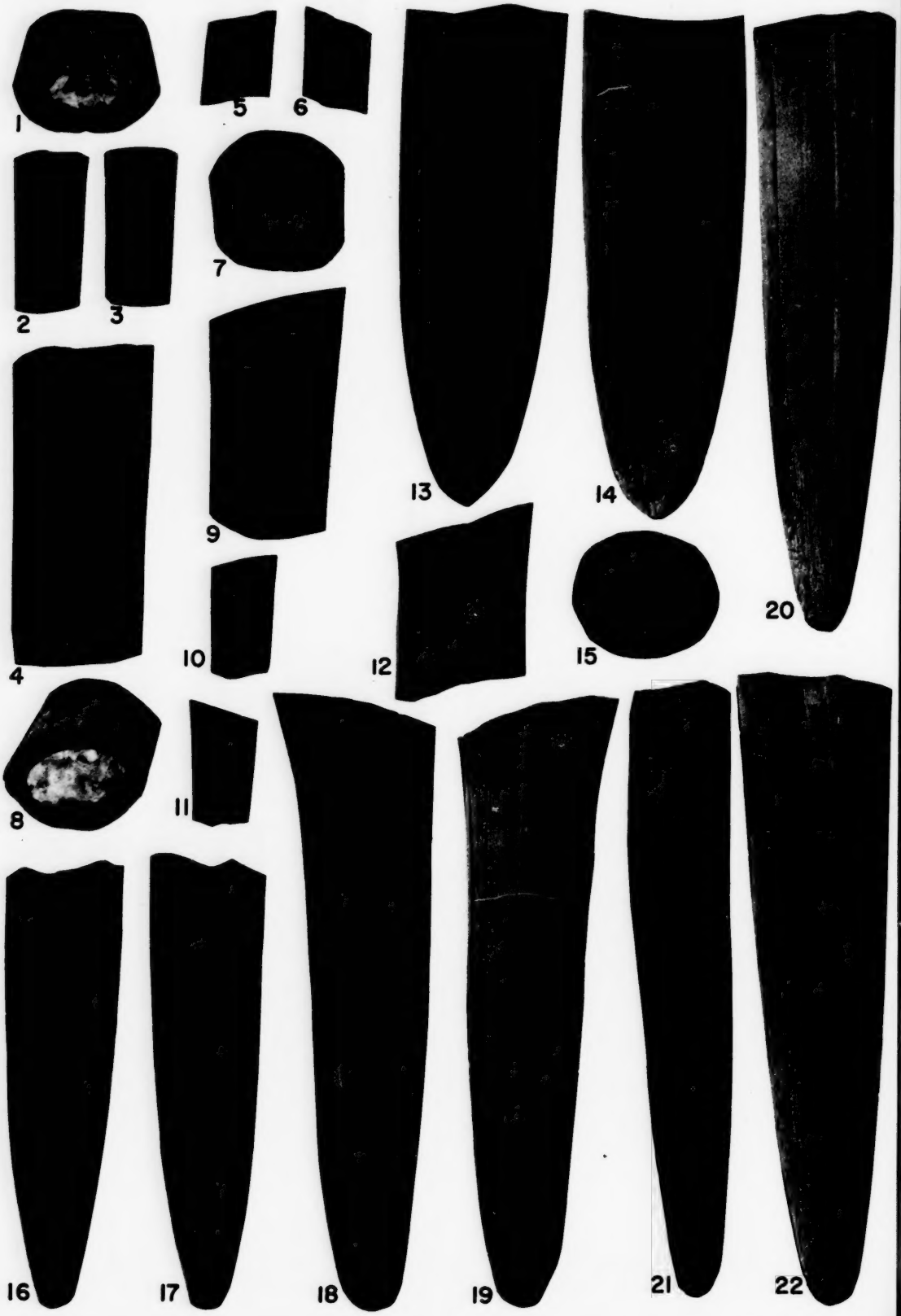
A second specimen, USNM 120027A, Pl. 115, figs. 5–7,12, shows a somewhat different arrangement of furrows. This is a fragment only 15 mm. long, slightly flattened, 10 by 8 mm. apically, the flattening essentially vertical, and showing at the apical end a phragmocone so crushed as to be semicircular, 4 mm. wide and 2 mm. high. The fine striae of the surface are numerous and somewhat variable in depth. Opposite the siphuncle, on the ventral side there is a rather wide band with only fine striae. On

---

EXPLANATION OF PLATE 114

FIGS. *1–25—Hematites barbarae* Flower & Gordon. Paratypes, showing variation in form and sculpture of the rostrum. All from the Chainman shale of the Burbank Hills, Utah. *1–8,11–14*—Three specimens showing variation in the form of the rostrum with the apex blunt, suggesting truncation of an epirostrum. See also Pl. 115, figs. 13–15. *1–4*, USNM 120024G. *1*, ventral side ×2, midventer at left, with close ventrolateral furrows on either side. *2,3* same specimen, ventral and dorsal sides. *4*, apical view ×2, venter below. *5–8*, USNM 120024F, specimen with apex constricted but striate, suggesting early stage after loss of epirostrum. *5*, ventral view ×2. *6* and *7*, ventral and dorsal views ×1. *8*, apical view ×2. venter above. *11* and *12*, ventral and dorsal views ×1 of another specimen, USNM 120024E. *13*, apical view ×2, venter below. *14*, dorsal view ×2. *9,10*. Opposite views of one of the largest fragments, USNM 120023B, ×1, curvature is abnormal, but probably organic, as it is normal to the plane of flattening of the anterior end. The midventral furrow is to the extreme right hardly visible in fig. 9. *15–17*. An early portion of a rostrum unique in the absence of furrows USNM 120024H; the callosity at midlength suggests the specimen to be the result of injury or disease, and is certainly abnormal. *15*, dorsal view and *16*, ventral view, both ×2. *17*, lateral view, venter on right, ×1. *18,19*. A form with unusually shallow striae and unusually broad flat interspaces, USNM 120024B, slightly flattened. *18*, venter ×2, with midventral furrow slightly to right of center. *19*, dorsal view ×2; dorsal striae not developed. *20,21*. Paratype, USNM 120024A, ×2. *20*, ventral view, with five furrows, the central three reaching the apex. *21*, opposite side, showing dorsal pair of furrows extending close to apex. *22,23*. Opposite sides ×1, of the longest fragment found, USNM 120023A. *22*, venter, with midventral furrow slightly to left of center. *23*, dorsal view, the faint pair of dorsal furrows apparent at midlength. *24,25*. Opposite sides of a crushed rostrum ×2, with unusually coarse striae, USNM 120023A. *24*, dorsal side; furrow on left obscure, the right one in the middle of the specimen, accentuated by crushing. *25*, ventral, showing the three prominent ventral furrows; note irregularity of longitudinal markings at tip.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25


1
5
6
2
3
7
13
14
20
4
9
10
12
15
8
11
16
17
18
19
21
22

either side of it is a group of furrows, those to the right rather widely spaced, two deep furrows alternating with three shallower ones. On the right, three deep furrows occur more closely spaced, without shallower ones between.

A third specimen, USNM 120027B, Pl. 115, figs. 8–11, is a fragment 21 mm. long, subcircular apically, but with a slight flattening of the dorsum, 8 mm. vertically, 9.5 mm. horizontally, increasing to 9 and 11 mm. at the anterior end, where a slightly oblique section was ground to clarify the siphuncle. The siphuncle is filled with calcite, but can be recognized, part of its wall being preserved, at the upper part of the phragmocone as oriented in Pl. 115, fig. 8, and a little to the right of the center. Here it is clearly spaced between two prominent furrows. These would appear to be good furrows flanking the venter, and appear as such on Pl. 115, figs. 9,10. However, to the left, as the specimen is oriented in these figures, there is only one other furrow, so faint as to appear secondary, while to the right, on the side and not clearly visible in the figure, are two additional strong furrows, one of which is apparent on the right side of Pl. 115, fig. 11. The remainder of the surface seen in this view, is marked by furrows so faint that they cannot be distinguished from the stronger of the striae.

It is an embarrassing fact that with the present wealth of material of *Hematites* from the Burbank Hills, it has seemed necessary to separate specifically this form with a pair of furrows flanking the venter instead of a midventral furrow, but we have been able to recognize relatively few specimens pertaining to this form. An interesting question arises as to the nature of the apex of *H. burbankensis*. No apices could be found in which a pair of ventral furrows and no midventral furrow extend to the tip of the rostrum. Yet it seems unlikely that we could have late stages of rostra of this species and no apices, for apices are quite abundant in the material. However, one specimen suggests that perhaps the midventral furrow is present apically, but becomes faint and finally completely lost in later growth stages. This specimen, USNM 120028, shown on Pl. 115, figs. 16, 17 is therefore referred tentatively to *H. burbankensis* but has not been designated a paratype. This is a rostrum 35 mm. long, increasing to 8 and 9 mm. adorally, showing at its adoral end a good conothecal cavity, but with neither septa nor siphuncle evident. This specimen shows a midventral furrow traceable for the entire length of the rostrum. However, while it is clearer than the other markings apically, it

---

EXPLANATION OF PLATE 115

FIGS. *1–12,16,17*—*Hematites burbankensis* Flower & Gordon. *1–4* Holotype, USNM 120026. *1*, adoral view, ×1, showing siphuncle on ventral side, above, with flanking ventral furrows. *2*, venter ×1. *3*, dorsum ×1. *4*, ventral view ×2. *5–7,12*, one paratype, USNM 120027A. *5*, venter ×1. *6*, dorsum ×1. *7*, adapical view ×2, venter above. *12*, venter ×2, showing close grouping of lateral furrows on left, more widely spaced ones on right. *8–11*, a second paratype, USNM 120027B. *8*, adoral view, with siphuncle indicated by white calcite at top of phragmocone, just right of center, with flanking furrows. *9*, ventral side ×2. *10*, venter ×1. *11*, dorsum ×1. *16* and *17*, USNM 120028, fragment of rostrum retaining apex, regarded as a young stage of the same species, ×2. *16*, ventral view, showing midventral furrow prominent apically, but obscure adorally where two pairs of lateral furrows become prominent. *17*, dorsal view.

13–15, 18–22—*Hematites barbarae* Flower & Gordon. *13–15*, paratype, USNM 120023C, ×2, an unusually gibbous specimen, slightly flattened. *13*, ventral side, one flattened side, with midventral furrow at left. *14*, dorsal view, right dorsal furrow at center accentuated by crushing. *15*, apex, with cruciform tip, venter above. *18,19*. Paratype, USNM 120024D, a laterally flattened individual with very fine striae. *18*, venter on right. *19*, opposite side, venter at left. *20–22*. Paratype, USNM 120023D, ×2. *20*, ventral side, showing left ventrolateral furrow farther from midventer than the one on the right, and furrow at left distant from midventral furrow, with an accessory furrow developed anteriorly; right ventrolateral furrow closer, with no accessory furrow. *21*, lateral view, venter at left; showing very faint anastomosing striae near apex. *22*, dorsal view, with dorsal furrows faintly developed below; anterior part slightly weathered.

becomes faint adorally. Shortly beyond the apex the primary ventrolateral furrows appear, and a little further orad a second pair appears between the primary ventrolateral furrows and the midventral one. Both primary and secondary ventrolateral furrows become very prominent adorally. This specimen suggests that with further growth, the midventral furrow may disappear and the two ventrolateral furrows may increase further in prominence, producing the effect seen in the later growth stages upon which *H. burbankensis* is based. The dorsal side of this specimen shows a faint pair of dorsal furrows with traces of fainter secondary furrows poorly differentiated from the numerous longitudinal striae.

Holotype.—USNM 120026.

Paratypes.—USNM 120027A,B.

Figured specimen.—*H.* cf. *H. burbankensis* USNM 120028.

Occurrence.—Chainman shale, middle part, USGS localities 15165 (primary types), and 17187 (figured specimen), Burbank Hills, Millard County, Utah.

BACTRITIMIMUS Flower and Gordon, n. gen.
Genotype, *Bactritimimus ulrichi*
Flower and Gordon, n. sp.

This genus is erected for belemnites which resemble *Hematites* as far as known in rostral features, but are set apart on the basis of the phragmocones which are strongly compressed in cross section. The sutures slope forward strongly from dorsum to venter, are sinuate, forming a broad dorsal lobe flanked by ventrolateral saddles which are separated by a V-shaped ventral lobe. The siphuncle is close to the venter, enough so that neck lobes may be apparent on the surfaces of internal molds. Septal necks are relatively long, slightly divergent at their tips.

The rostrum is known only from a few fragments adhering to the phragmocones, which do not show its shape or the nature of its apex. They bear numerous longitudinal striae and fainter transverse striae. The longitudinal striae are broader than in *Hematites*, and the transverse striae cross not only the interspaces, but continue across the longitudinal striae. It is not certain, however, that these differences are necessarily of generic significance. The material shows some additional furrows on the rostral surface, but their number and arrangement cannot be determined.

Discussion.—Though little is yet known of the rostrum of this genus, its features are evidently closely similar to those of *Hematites* and *Aulacoceras*. It must await further material to determine whether the slight differences now apparent in the rostral surface are of generic significance or not, particularly in view of the variability in these features already evident in *Hematites barbarae*. The salient features of the genus are the strong compression of the phragmocone and its strongly oblique and sinuous sutures. Such features could be expected in modifications of *Hematites* which still might be included in the genus, but the V-shaped ventral lobe is not, and apparently the siphuncle has relatively long septal necks, more like those of *Eobelemnites* and *Paleoconus* than those of *Hematites*. The position of the siphuncle so close to the venter that neck lobes are developed on the surface of the internal mold of the phragmocone, supplies an additional distinction from *Hematites*.

The features of the phragmocone of this genus are closely comparable to those of a number of the five genera which Shimansky (1954) has described as constituting the family Parabactritidae. Indeed, were it not for a fragment of a rostrum attached to the holotype of *Bactritimimus ulrichi*, it would have been difficult, perhaps impossible to prove that our present forms were belemnoids and not bactritids, a matter which is discussed more fully following the descriptions of the present species. It may, however, be noted here that the implications are strong that some of the supposed bactritids of the late Paleozoic may be based upon phragmocones exfoliated from belemnoids.

The present material of *Bactritimimus* constitutes only four specimens from a single locality. Anomalously, the two better preserved specimens obviously represent different species, for though they are essentially the same size, indicating that differences cannot be attributed to changes developed in progressive growth, they show definite differences in rate of expansion, cross section of shell and siphuncle, sinuosity and lobation of the sutures, which must be of a specific significance. Two smaller fragments

show a general correspondence to these same two species, but show differences of sufficient magnitude to make their identification with them somewhat doubtful.

BACTRITIMIMUS ULRICHI Flower and Gordon, n. sp.
Pl. 112, figs. 1–4

This species has a small slender phragmocone, the apical angle 5–6° horizontally and 8–9° vertically; cross section compressed, dorsum only slightly more broadly rounded than venter, greatest shell width attained only slightly dorsad of midheight. The septum attains its greatest depth on the dorsal third of the specimen, curves forward strongly dorsally and laterally, but its curvature as it approaches the venter is much more gentle. Sutures slope forward from dorsum to venter, having a dorsal lobe so broad that the suture appears transverse when the shell is viewed from the dorsal side, but the sutures curve forward dorsolaterally, the convexity directed apicad, as they slope gradually forward toward the venter. Ventrolateral saddles are scarcely convex orad, but are separated by a small V-shaped ventral lobe which is not, in our present material, modified by the appearance of a neck lobe on the surface of the internal mold. The siphuncle is small, circular, and narrowly separated from the venter.

Fragments of the rostrum adhering to the wall of the phragmocone show broad rounded longitudinal striae separating elevated interspaces which are rounded rather than flattened as in *Hematities;* both interspaces and longitudinal striae are traversed by finer transverse striae. There is a suggestion of furrows on the rostrum, possibly a deep ventrolateral pair and a midventral furrow, but the present fragments of the rostrum are inadequate to show the pattern with certainty.

The holotype shows at its base a septum 9.5 mm. high and 7.5 mm. wide, the venter only slightly more narrowly rounded than the dorsum, and the greatest shell width attained only very slightly dorsad of the center. The siphuncle is circular in cross section at the septal foramen, 1.2 mm. across, and very narrowly separated from the venter. The greatest depth of the septum is attained on the dorsal third of the shell. The septal depth is about one-fourth the height of the shell. Orad of the basal septum of the type, the shell wall extends forward for varying lengths around the circumference of the specimen ranging up to 6 mm. In addition to the basal septum at the base of the specimen, one other is preserved, showing the camera to be 3 mm. long.

The sutures have already been described, and are shown amply in the accompanying illustrations. In contrast to *B. girtyi*, the obliquity and sinuosity are both slight, and it may be noted that where the suture bends apicad from the ventrolateral region toward the dorsum, it is curved, convexity directed apicad, rather than orad as in *B.* cf. *ulrichi.* The wall of the phragmocone shows a smooth polished appearance for the most part. Orad of the apical septum is a strongly incised septal line; otherwise the surface of the phragmocone bears only very fine faint longitudinal markings. The septal line is slightly closer to the suture ventrolaterally than eleswhere; both septum and septal line show development of similar V-shaped ventral lobes.

Though portions of the rostrum adhere to the surface of the phragmocone, the specimen fails to show any indication of the expected three layers of the conotheca; neither are there any traces preserved of conothecal striae. The rostrum surrounding the phragmocone is thin, 0.6 mm. at the level of the septum, and thinning slightly adorally. Clearly, the rostrum was compressed in section as is the phragmocone, for it shows no increase in thickness when traced from the ventral to the lateral regions. Dorsally neither rostrum nor wall of the phragmocone can be seen; apparently the shell was broken here prior to burial.

Discussion.—The species rests upon the the unique holotype which, in spite of its fragmentary condition, shows the essential features of the phragmocone and also fragments of the rostrum without which the belemnoid nature of this genus would not have been evident. The associated *B. girtyi* has a more rapidly expanding phragmocone, with cross section considerably more broadly rounded dorsally than ventrally, greatest shell width attained well dorsad of the center of the cross section, the siphuncle in flattened contact with the ventral wall of the

shell at the septal foramen, instead of rounded. The sutures are more oblique, more strongly sinuate, the ventral lobe larger, ventrolateral saddles more rounded, with a strong reversal of curvature as they descend laterally to the dorsal lobe. *B.* cf. *ulrichi*, as noted below, agrees with *B. ulrichi* in the slender phragmocone and spacing of the sutures, but the curvature of the sutures is somewhat different, and prominent neck lobes are developed on the surface of the internal mold.

Holotype.—USNM 119690.

Occurrence.—Fayetteville shale, base of 15-foot limestone unit, about 80 feet below the top of the formation, USGS locality 1625, hill about a half mile southeast of Marshall, Searcy County, Arkansas.

BACTRITIMIMUS sp. cf. *B.* ULRICHI
Flower and Gordon
Pl. 113, figs. 29–31

Under this name is figured and described a small fragment of phragmocone, agreeing with *B. ulrichi* in apparent rate of expansion and spacing of the septa, but differing from it in the conformation of the sutures and in the development of prominent neck lobes. The fragment retains only a small part of the internal mold of a phragmocone, about half of the shell, retaining slightly more than the venter on the left, and not quite attaining the dorsum on the right. The fragment is 5.5 mm. in length, in which the shell apparently expands at a moderate rate. Two septa are 2 mm. apart. In front of each septum is a clear septal line, one-fifth to one-sixth the distance forward to the next septum. The sutures and the septal line slope forward from the dorsolateral limit of the specimen toward the venter, arching, convex orad, then becoming more transverse and nearly straight over a broad ventrolateral region. The broad ventrolateral saddles thus produced are interrupted by a small ventral lobe, the conformation of which varies between the two exposed septa. The apical septum curves apicad ventrally forming a neck lobe, and the tip of the neck is very slightly recurved, and its termination is free and abrupt. The septal line here slopes apicad, but the slope is not quite as great as that of the septum, and it meets the septal line of the opposite side forming a broad V-shaped lobe. The anterior septum shows the septal necks developing a neck lobe, but here the lobe is broader and its apparent width is exaggerated to the eye because the septal line, which can be seen on either side of the ventral lobe, is wanting midventrally.

The surface of the internal mold presents a polished appearance. Ventrolaterally there is a faint single longitudinal striation, which it has proved impossible to show properly in our photographs, though it can be seen faintly to the left of the center in Pl. 113, fig. 29, and faintly at the extreme right of Pl. 113, fig. 31. The material between the septa and the septal line is for the most part on a level with the rest of the shell surface, but there are places where this material is removed, and there one sees a slightly concave surface, smooth, polished, as one would expect where a small bit of shell substance, here evidently a much reduced cameral deposit, is removed with the shell wall.

Discussion.—Though this small fragment agrees with *B. ulrichi* in general proportions, apparent rate of expansion and spacing of the septa, the conformation of its sutures is quite different. Clearly the present material is inadequate to show whether this form is a distinct species, or whether *B. ulrichi* is a species exhibiting some greater variability on the course of the sutures and in the development of a neck lobe, than experience would lead one to believe.

Figured specimen.—USNM 120029.

Occurrence.—Fayetteville shale, from the same locality and horizon as *B. ulrichi* and *B. girtyi*, USGS locality 1619, hill a half mile southeast of Marshall, Searcy County, Arkansas.

BACTRITIMIMUS GIRTYI Flower and Gordon, n. sp.
Pl. 112, figs. 5–11; pl. 113, figs. 1,2

This species is known only from a portion of a phragmocone, and shows nothing of the conotheca or rostrum. It agrees with *B. ulrichi* in general aspect, but is more rapidly expanding, shows a markedly greater rate of expansion vertically than horizontally, has the cross section more broadly rounded dorsally with the greatest shell width attained well dorsad of the center of the cross section, the septal foramen of the siphuncle

is flattened ventrally where it is in contact with the ventral side of the shell. There are differences also in the curvature of the septum, the sutures are more strongly oblique and more strongly sinuate, the ventrolateral lobes being definitely but broadly rounded and the midventral lobe more strongly developed.

The holotype is a small portion of a phragmocone not quite complete dorsally. The septum at its base shows the dorsum more broadly rounded than the venter, and in its present condition is 8.5 mm. high but was probably between 9.0 and 9.5 mm. high when complete; the corresponding width is 7.8 mm. In vertical profile the smooth polished septum is strongly curved dorsally, and slopes forward with its curvature decreasing as it approaches the venter. The septal foramen is 1.2 mm. wide and 0.8 mm. high; its dorsal margin is circular, but ventrally the circle is truncated by the broader arc of the ventral margin of the shell. The shell walls extend forward from the basal septum for a maximum length of 7 mm. showing two sutures in addition to that of the basal septum. Camerae are 1.9 mm. in length. The shell expands horizontally at an angle of 11°, the vertical apical angle is 14–15°.

The sutures show a broad V-shaped ventral lobe, very gently rounded at its extreme center. In spite of flattening of the septal foramen by the ventral wall of the shell, the anterior suture shows no trace whatsoever of the neck lobe, and it is only obscurely developed in the apical septum. The septal line is developed as a narrow shallow incised line. The area between it and the suture is markedly darker than the remainder of the surface of the phragmocone, but both parts show a polished surface on which very fine longitudinal striae are developed, with tiny raised dots apparent under the highest magnification. As the septal line outlines a ventral lobe, it becomes somewhat more rounded in its course than does the true septum. The dark polished material between septum and septal line has a sharp apical boundary ventrally, this boundary obscuring the neck lobe where it is developed. Ventrolateral saddles are broadly convex adorally; the suture slopes apicad dorsally and reverses its curvature. The dorsal lobe, incompletely preserved, is apparently very shallow, broad, and nearly transverse.

The same association has yielded a fragment showing the left side of two camerae. The specimen (Pl. 112, figs. 9–11) retains part of the middorsal area, but fails to attain the midventral region and lacks the siphuncle. The greatest distance across is 8 mm. and the two camerae together are only 2.8 mm. long. The whole specimen shows slight distortion. A rather rapid rate of expansion, comparable to *B. girtyi* is suggested, but the sutures appear somewhat less sinuous and less strongly oblique. Evidently the specimen, when complete, was somewhat larger in cross section than the type of *B. girtyi*, and the differences shown could be a combination of variations between ontogenetic stages and the slight distortion.

Many, indeed most, orthoconic nautiloids show adoral camerae which are crowded, and in which the lobation of the sutures may be slightly modified, and, usually, simplified. There is some indication that such a crowding of camerae is also a feature of the late growth stages of belemnoids.

Discussion.—Although the material of this species shows only the phragmocone, with no indication of the structure of the conotheca or rostrum, its close affinities with the associated *B. ulrichi* leave no real doubt as to its belemnite affinities. The features by which the species are distinguished are largely details of proportion, and have already been noted. Indeed, the differences are such as might possibly be expected between different growth stages of a single species, but this explanation cannot be the true one, for the specimens from which the two species are known are essentially commensurate.

Types.—Holotype, USNM 119689. Figured specimen tentatively assigned to the species, USNM 120030.

Occurrence.—Fayetteville shale, base of 15-foot limestone, about 80 feet below the top of the formation, USGS locality 1619, hill about one-half mile southeast of Marshall, Searcy County, Arkansas.

BELEMNOID AND BACTRITID PHRAGMOCONES

A very close similarity exists between the phragmocones, eliminating features of the conotheca and rostrum, of the known Mississippian belemnoids and a number of late

Paleozoic fossils which have been described as bactritids. Indeed, so close is the similarity, that had it not been for portions of rostra attached to the phragmocones of *Hematites barbarae* (Pl. 113, figs. 10–13) and *Bactritimus ulrichi* (Pl. 112, figs. 1,2) it would have been impossible to demonstrate that they pertained to belemnoids and not bactritids. The similarity suggests further lines of inquiry: can isolated phragmocones of bactritids and belemnoids be distinguished with certainty? If one accepts the attributions to these groups as they are made at present, the answer is certainly no. But a further question is also suggested: have some isolated belemnoid phragmocones been misidentified in the past as bactritids? If so, is this misidentification responsible for the apparent very close merging of the features of belemnoid and bactritid phragmocones?

Without attempting to delve into the extensive literature concerning the bactritids, let us say for purposes of the present discussion that we regard the bactritids as a group of orthocones stemming from the Michelinoceratida and not the true ancestors of the Ammonoidea. Of the supposed bactritids one should be eliminated, the genus *Eobactrites*, which is of late Canadian age, and thus isolated stratigraphically from the next oldest bactritid, that of the Lower Devonian. We regard *Eobactrites* as a member of the family Baltoceratidae, closely allied to *Wolungoceras* of the late Canadian of Manchuria. It possesses the thick connecting rings of the Ellesmeroceratida.

The nucleus of the true Bactritidae is a group of small slender Devonian orthoconic shells which we have every reason to believe were external. Specimens are known with good and essentially complete living chambers. Some forms had shells that are thin and smooth, but others show surface markings comparable with those of other cephalopods with external shells (Horný, 1957).

In the late Paleozoic, however, we find two general types of bactritids: one with very gradually expanding shells and long camerae, and the other with rather rapidly expanding shells and short camerae. The latter type is so far known only from phragmocones. In general features these phragmocones are of bactritid aspect, but they also approach the phragmocones of our present described Mississippian belemonoids very closely. While no definite conclusion is possible, an analysis of the evidence suggests a very close relationship between the bactritids of this sort and the belemnoids, enough so to raise the question as to whether some at least of the supposed bactritids could be exfoliated belemnoid phragmocones.

Family PARABACTRITIDAE Shimansky 1954

The following analysis of the Parabactritidae, which was described in Russian, was made possible by two translations, one by Ivan J. Mittin of the U. S. Geological Survey, the other made, with the help of the senior author, by Mme. Tatiana Vacquier.

The family Parabactritidae is based upon a series of shells, apparently all of which are known from phragmocones without living chambers. They were differentiated from the Bactritidae by being more rapidly expanding and having the septa more closely spaced. Some specimens are only internal molds of phragmocones; others show a thin covering of shell, smooth or only with markings of very faint relief. The genera are characterized as follows, the original descriptions being emended somewhat owing to occasional confusion in the original descriptions of the neck lobe with the true ventral lobe, and occasional cases where the ventral lobe seems to have been described on the basis not of the course of the suture, but of the septal line instead.

Parabactrites.—Shell relatively slender, cross section only slightly compressed, lateral regions broadly and uniformly rounded, dorsum and venter more narrowly rounded than sides, but subequal with each other. Sutures transverse, with no lateral lobes. Suture interrupted ventrally by neck lobes which are straight, extend for about a third the length of the camera. A horizontal longitudinal section through the siphuncle shows the necks very faintly divergent basally, but becoming subparallel apically. The septal line is well shown on one specimen (Shimansky, 1954, Pl. 10, fig. 7) and are straight and transverse except midventrally; there they form broad V-shaped lobes equal in width to the neck lobes of the suture. One specimen, somewhat more rapidly expanding than the others, and thus

doubtfully conspecific with them, shows some shell covering the phragmocone. This shell is thin, essentially smooth, bearing flat transverse raised bands of extremely low relief, visible only under a lens.

Tabantaloceras.—Cross section compressed, sides strongly flattened, venter more narrowly rounded than dorsum, shell increasing somewhat more rapidly vertically than horizontally, so that compression of the cross section increases as growth progresses. Sutures are normal to the shell axis, bear low broad rounded lobes, convex apicad on the lateral sides, separated by dorsal and ventral crests. The ventral crest is modified by a neck lobe, which shows the necks divergent at their bases, but parallel at their tips, and extending apicad for about half the length of the camera. The septal line is not clearly evident. The shell surface is reported as smooth, and with a septal furrow on the middorsal region of the phragmocone. The one species is represented by two figured specimens.

Aktastioceras.—A moderately slender shell, cross section more compressed than in *Parabactrites*, but without the prominent flattening of the sides of *Tabantaloceras*. The rate of expansion of the shell is only slightly greater vertically than horizontally. Sutures show shallow rounded lateral lobes, but are essentially transverse over the ventral side. There they are somewhat variable (Shimansky, 1954, Pl. 11, fig. 8) for some sutures show a well developed neck lobe, while others do not. Where developed, the neck lobe shows the necks slightly divergent basally, parallel apically, and extending for about half the length of a camera. Other sutures vary between being perfectly transverse ventrally, and showing the faintest suggestion of a midventral lobe. The shell surface is stated to be smooth. It is not shown on any of the three figured specimens.

Microbactrites.—This genus is based upon a series of two phragmocones, much more rapidly expanding vertically than horizontally, and showing a cross section which becomes increasingly compressed as growth progresses. Septa are quite closely spaced, modified ventrally by neck lobes which, as in the other genera, diverge basally and are parallel apically. The true ventral lobe is very small or absent. The surface of the phragmocone is marked with rather distant furrows which are rather strongly oblique. The sutures are reported as oblique, presumably sloping ventrorad, and are crossed by the transverse bands. Some difficulty attends interpretation of the genus, for neither the descriptions nor the explanations of the plates indicate clearly whether either the sutures or the surface markings slope forward on the venter or on the dorsum. If sutures slope forward dorsally, the genus is comparable with *Eobelemnites;* if on the venter, with *Hematites* and *Bactritimimus*. Neither of these genera show broad oblique bands on the surface of the phragmocone. *Eobelemnites* is reminiscent of *Microbactrites* in the rapid rate of expansion of the phragmocone vertically. The phragmocones of *Hematites* and *Bactritimimus* are more slender; in the latter genus the sutures are quite strongly oblique and sinuous; in the former they are unlobed and their departure from the transverse is slight.

Belemnitomimus.—This phragmocone is circular in cross section and quite rapidly expanding, with very close sutures. As the shell is oriented in lateral view with the sutures normal to the axis, one side is markedly more oblique than the other, but descriptions and illustrations fail to indicate whether it is the dorsum or venter that is the more oblique. This obliquity yields also the faintest suggestion of curvature of the phragmocone, but insufficient data on orientation do not permit one to say whether such curvature is exogastric or endogastric, unfortunately a question of some importance. Sutures are faintly sinuous, but lobation is very slight. The ventral side shows faint close neck lobes, terminating in triangular or trapezoidal areas on the apical end of each camera wall. A vertical section shows that this area marks the flattened contact of an expanded and somewhat scalariform siphuncle segment with the ventral wall of the shell. The septal neck is short and sharply recurved dorsally, longer and sinuate ventrally, as in *Hematites*, but in that genus the remainder of the segment is not broadly expanded, and the gross aspects of its phragmocone do not resemble those of *Belemnitomimus* at all closely. The figures suggest that Shimansky's (1954) Pl. 12, fig. 1A has the siphuncle on the right.

If so, the sutures slope forward slightly on the dorsum, and it is that side which is very slightly concave.

MISSISSIPPIAN BELEMNOID PHRAGMOCONES

From the above summary, it is evident that there is a strong general resemblance between the phragmocones of the Parabactritidae and those of the Mississippian belemnites described in the present work. This may be emphasized further by a summary of the phragmocones of the four known Mississippian belemnite genera:

Eobelemnites.—Phragmocone rapidly expanding vertically, becoming increasingly compressed in cross section as growth progresses. Sutures slope forward from venter to dorsum, but are not lobed or sinuate. Septal necks do not form neck lobes on the surface of the internal mold, but are divergent basally, subparallel apically, and rather long, like the necks of *Parabactrites*, *Aktastioceras* and *Tabantaloceras*. Inner layers of the conotheca are smooth, bearing faint transverse bands of tiny raised dots, visible only under magnification.

Paleoconus.—The surface of the phragmocone of this genus has not been observed. It is evidently moderately expanding, circular in cross section, the sutures transverse, not oblique. There is no reason to suspect the presence of any lateral lobes. Siphuncle with rather long necks, in general similar to those of *Eobelemnites* and *Parabactrites*, but somewhat removed from the venter, so that its expression as a neck lobe is most unlikely.

Hematites.—The phragmocone is moderately slender, compressed slightly, with vertical and horizontal rates of expansion about equal. Sutures slope forward very slightly from dorsum to venter, but are unlobed. Septal neck recurved dorsally, sinuate ventrally, more like that of *Belemnitomimus* than any of the other genera or the Parabactritidae, but without the apical part of the segment inflated. No examples are known in which the siphuncle is expressed on the surface of the phragmocone. In young stages the siphuncle is definitely removed from the venter, though this does not appear to hold for later growth stages. As noted below some supposed *Bactrites* have phragmocones quite similar to that of *Hematites*.

Bactritimimus.—Here the phragmocone is more strongly compressed, the sutures slope more strongly forward from dorsum to venter, are sinuate, and develop a true ventral lobe. The expression of neck lobes on the surface of the phragmocone is variable. Necks are long, divergent basally. They are not as long as in *Parabactrites* and fail to show the subparallel tips characteristic of that genus and some of its allies.

A comparison of descriptions and of our illustrations with those of Shimansky (1954) will show that while none of our phragmocones are close enough to any of those which he figures to be considered congeneric, the relationship is nevertheless a very close one. The similarity raises several important questions. It is plain, from the attached rostra, that our specimens cannot be members of the Parabactritidae. Is it not, however, possible that at least some of the Parabactritidae could be based upon belemnoid phragmocones from which the rostrum has been exfoliated? The possibility seems a real one. Such shell surfaces as are reported for the family seem for the most part, to be smooth or to bear markings only of the faintest relief; indeed, markings of such a nature that it would not be difficult to interpret them as very fine sculpture upon one or both of the two inner thin layers of a conotheca.

In support of this interpretation, it may be noted that none of Shimansky's figured specimens show a living chamber. Shimansky does note a "large" living chamber for *Microbactrites*, but his meaning here is not altogether clear; he may be referring only to the relatively large diameters attained at the adoral end of these rather rapidly expanding portions of phragmocones. It is not evident however, that their anterior ends are properly interpreted as true living chambers. While this negative evidence is of limited value, the absence of a true living chamber in any of the material does tend to support the possibility that these phragmocones might belong to belemnites.

One bit of evidence, however, seems to oppose the interpretation of Shimansky's specimens as belemnoids: the apparently thick wall of the shell shown for *Parabactrites* on his Pl. 10, fig. 4. However, it may well be that the large magnification here is deceptive; close analysis shows that the

shell wall here is scarcely thicker than the septa, a condition paralleled by our sections of *Hematites*.

Still another possibility may be suggested: that the Parabactritidae were internal shells, but belong to belemnoids lacking well calcified rostra. Such shells are known, and constitute the family Chitinoteuthidae (Müller-Stoll, 1936). They are known in the Lias, but not as yet in earlier beds. The possibility has been suggested (Roger, 1952) that the Chitinoteuthidae may represent the archaic stock of the belemnoids. If so, we may expect to find them in earlier strata. While the idea is worthy of mention in this connection, it is necessary to note that the theory underlying it may be unsound. The Chitinoteuthidae are not necessarily primitive. Granting that the origin of the belemnoids is marked by the mantle growing over the shell and the secretion of a rostrum upon its surface, there seems to be no really good reason for supposing the primitive rostrum to have been chitinous. The mantle of the cephalopod with an external shell was already so developed physiologically as to be capable of secreting a shell which was essentially calcareous and, from all indications, primarily aragonitic. It would seem much more logical for the first belemnoid rostra to be aragonitic than chitinous, for it would seem that there would be less marked physiological changes to be required as accompanying the structural changes. It would then appear as logical that the development of a chitinous rostrum in the Liassic Chitinoteuthidae may well be a specialized condition, as our present stratigraphic evidence would suggest, rather than a primitive one.

One other suggestion of the close affinities of belemnoid phragmocones with supposed bactritids is found. Youngquist (1949) described from the White Pine shale of former usage of Nevada a moderate sized phragmocone of bactritid aspect as *Bactrites nevadense*. It is only slightly more slender than some of the belemnoid phragmocones described here, and is of particular interest because it also comes from the Mississippian; indeed, its provenance is not far removed from that of our *Hematites barbarae* of the Burbank Hills of Utah. It differs from *Hematites* in being somewhat more strongly compressed in cross section, and in having the sutures transverse, instead of sloping foward ventrally very slightly, and shows very broad shallow lateral lobes.

The similarity is, however, close enough to be most suggestive of possible relationships, and this suggestion is carried further by yet another specimen. This is a small portion of a phragmocone of bactritid aspect, from the Perdido formation at the northern end of the Panamint Range, in Death Valley, California (Stanford University Collection). This shell is only a small fragment, and was first identified with *Bactrites nevadensis*, but it is slightly more broadly rounded in cross section, has perhaps slightly more closely spaced septa, and is slightly more rapidly expanding. Its sutures appear to lack lateral lobes, but slope gently dorsorad. It is, then, extremely close in the features of its phragmocone to *Hematites*. Some shell material is found on the wall of the phragmocone, but its surface is unmarked except that it is faintly granular. There is clearly no rostral material around this specimen, but this proves nothing.

The phragmocone of *Eobelemnites* extends far forward from the rostrum. It may do so in other belemnoid genera. True, such material is rarely found, but the unsupported phragmocones are susceptible to destruction prior to burial, and compaction in shaly sediments is a further hazard in their preservation. It is particularly interesting that this specimen, which from casual inspection one would identify as a bactritid and one very close to the Parabactritidae of Shimansky, shows features of the phragmocone essentially identical with those of *Hematites*, concerning the belemnoid nature of which there can be no possible doubt.

Shimansky (1954) has attempted to find differences between the phragmocones of the older belemnoids and the bactritid cephalopods. The differences which he cites are not fully substantiated by the older literature, and are made the more unsafe by our present findings. He suggests as one difference the relatively long septal necks of the bractritids, in contrast to the short ones of the "atracitids." However, Mojsisovics (1902, suppl. Pl. 16, fig. 1A) has figured for "*Atractites*" *convergens* necks so long that they extend for two-thirds to three-fourths

the length of the camerae. Also, they are divergent basally, and subparallel apically, very much like those of the Parabactritidae. Similar long necks are known in the Mississippian genera *Eobelemnites*, *Paleoconus* and *Bactritimimus*.

Shimansky states also that the "atractid" shells are much larger than bactritids. Early stages are, however, tiny (von Bulow, 1915, Pl. 58, fig. 3). Mojsisovics (1882, Pl. 92, figs. 7–9) has figured some minute phragmocones assigned to *Atractites*, which are commensurate with the smaller bactritids and, in fact, resemble them closely in structure. Some of our present Mississippian forms have phragmocones essentially commensurate with some bactritids which Shimansky describes, and it may be noted further that some bactritid fragments have been described from the Permian which, by the cross sections of their shells are fully as large as most specimens of *Ausseites* in the Triassic.

IMPLICATIONS OF THE PRESENT STUDY

The present material, together with the previously described *Eobelemnites caneyensis*, brings the number of known Mississippian belemnoid genera to four, and the named species to six. It seeems pertinent to note the effect of these forms upon some previous ideas, and some previously stated questions relating to belemnoid classification, morphology and phylogeny. Not all of the questions are answered by the present material, but some contribution is made to certain problems, and other new ones are raised.

The family Aulacoceratidae.—There has in the past been a rather general agreement that the older belemnoids, those of the Triassic, were different enough from the younger Belemnitidae to be set apart in the family Aulacoceratidae, but there has been no general agreement as to how this family can be distinguished. It is necessary to consider two aspects of this question, first, whether the Aulacoceratidae, as formerly understood as embracing essentially the known Triassic belemnoid genera, has any real identity apart from the Belemnitidae, and second, if so, whether the Mississippian forms fit properly into such a family. Confusion as to the terms in which the Aulacoceratidae is defined have already been discussed (Flower, 1944, 1945, Fischer, 1951). It has been suggested that the rostrum of the Aulacoceratidae extends forward not only in a long anterior dorsal crest, but also in a short ventral one. Proostraca are completely unknown for Triassic belemnoids of this sort, though they are known for the Triassic belemnoteuthid *Phragmoteuthis* (Mojsisovics, 1882, Pl. 95). In the belemnoids with massive rostra, the nature of the proostracum can be inferred from the pattern of the growth lines on the conotheca. Unfortunately such conothecal striae can be seen only on conothecal surfaces from which the rostrum has been exfoliated, or on those which are found preserved orad of the anterior limits of the rostrum. Both conditions of preservation are extremely rare. Mojsisovics has figured only a few species of *Dictyoconites* showing the conothecal striae (1902, supp. Pl. 13, fig. 7, for *Dictyoconites quadrilineatus*, supp. Pl. 14, figs. 1–5, *D. brancoi*, *D. deineri* and *D. reticulatus*, supp. Pl. 15, fig. 4, for *D. haughi*). While the evidence is sufficient to show that some Triassic genera and species have such conothecal markings and therefore the type of proostracum attributed to the Aulacoceratidae, it is another and a much broader assumption to attribute such a feature to the Aulacoceratidae and to include in the family all of the Triassic belemnites with large rostra. Conothecal striae have as far as we have been able to find, never been described for species of *Aulacoceras* or *Ausseites* (= *Atractites* of authors). Curiously. *Eobelemnites caneyensis*, though known only from a single specimen, shows on that specimen beautifully preserved conothecal striae. Further, these striae agree with the pattern found in *Dictyoconites* and attributed to the Aulacoceratidae. It is necessary to conclude that the present evidence is sufficient to indicate that some Mississippian to Triassic genera have a short forward projecting crest of the proostracum on the venter. Such a structure is not known in any of the Jurassic or Cretaceous genera, but it is not evident that all of the older forms have this feature in common.

Roger (1952) recognizes the Aulacoceratidae, and emphasizes as a basis of its recognition the resemblance of its phragmocone to those of Michelinoceratida and the

bactritids. We have already pointed out how strong this similarity is for Mississipian forms, but it is not quite as clear what is meant in reference to the Triassic species. It appears to be quite generally true that the Triassic genera usually placed in the Aulacoceratidae do have phragmocones which are better calcified than those of the Jurassic and Cretaceous Belemnitidae, but this difference is not a sharp one. Triassic forms, also, agree in general in having the septa rather widely spaced, in contrast to which the septa of Jurassic and Cretaceous Belemnitidae are, in general, both thinner and more closely spaced, but this difference is not a sharp one. Indeed, our Mississippian genera *Eobelemnites* and *Paleoconus* appear in this respect to be closer to the Belemnitidae than to the Aulacoceratidae.

It was suggested by Dr. Leslie Barstow (fide litt., to Flower) that the Aulacoceratidae possess rostra in general which are fibrous, containing considerable organic matter, while the rostra of the Belemnitidae showed finer structure of their radial elements, and were essentially calcareous. The fibrous organic rostrum appears to be quite characteristic of *Aulacoceras*, *Asteroconites* and *Dictyoconites*, and is certainly shared by the Mississippian genus *Hematites* and probably by *Bactritimimus*. It is, however, certainly not shown by *Eobelemnites*, and though pyritization leaves the original fine structure of the rostrum of *Paleoconus* somewhat uncertain, its aspect suggests that it should be grouped with *Eobelemnites* in this respect rather than with *Aulococeras*. There remain a number of Triassic genera, for which the rostrum seems to be calcitic rather than fibrous and organic, *Ausseites*, *Choanoteuthis* and *Metabelemnites*, while some of the remaining described genera cannot, from the published descriptions or figures, be assigned to either category with certainty.

One must conclude that the structure of the rostrum fails, in the present state of our knowledge, to supply a good basis for distinguishing Aulacoceratidae and Belemnitidae. If such a division is to be accepted, however, it will be necessary to postulate that some Mississippian and Triassic genera are true Belemnitidae, and all of these older genera could not be placed in a family Aulacoceratidae. In the following discussions, the family Belemnitidae is employed as embracing the former Aulacoceratidae.

The living chamber.—The concept that among the older belemnoids there were some forms in which there was a true tubular living chamber with a relatively transverse aperture, appears now and again, but seems to have no real substantiation. Naef (1922) has found the evidence of such a condition to be very poorly supported. What has often been considered a living chamber which supposedly existed at the anterior end of a belemnoid phragmocone, is based upon living chambers of "*Orthoceras*," now properly *Michelinoceras*, which occasionally are found associated with belemnoid remans. Curiously, our own material offered a similar temptation to identify a living chamber from some member of the Michelinoceratida with belemnoid phragmocones. Such a living chamber was found at USGS locality 1619, associated with *Bactritimimus ulrichi* and *B. girtyi*, but happily it was possible to demonstrate that it had no real relationship with these species. It was the anterior part of the internal mold of a living chamber, and evidently, a mature one, for it showed a constriction at its base, which represents the internal thickening of the shell which occurs just prior to the aperture in mature individuals of many Michelinoceratida. Had such a living chamber pertained to either of these belemnoid species it would, of necessity, show a diameter considerably greater than that of the phragmocones owing to the conical adoral expansion of the shells. This form was essentially commensurate with the belemnoid phragmocones; clearly it belonged to a relatively tiny orthoconic nautiloid. Even had this difference not been a conclusive one, the disparate nature of the belemnoids and this nautiloid living chamber was shown by discrepancies in their cross sections, for the orthoceran living chamber was subcircular in cross section, and the belemnoid phragmocones were strongly compressed.

It is, of course, also obvious that living chambers of nautiloid aspect could not be developed in belemnoids which show such patterns as are exhibited by the conothecal striae known in *Dictyoconites* and *Eobelemnites*. However, the matter deserves con-

sideration in relation to our Mississippian forms, *Paleoconus*, *Hematites*, and *Bactritimimus*, which are not as yet represented by any specimens showing the conothecal striae. There is, however, no reason to believe that the absence of such striae in these forms is the result of anything more than the unsuitable preservation of the known specimens for the demonstration of this feature. There is no reason to believe that they had anything approaching an orthoceran living chamber.

In this connection it is worthy of note that long and complete living chambers are known for quite a large number of Devonian Bactritidae with relatively smooth thin shells, as *Bactrities arkonensis* (Whiteaves) and *Lobobactrites clavus* (Hall). The Genundewa limestone lentil of Late Devonian age of western New York has yielded abundant *Bactrites* with long living chambers. This form has commonly been identified in terms of the species *B. aciculum*, a species based upon such poor flattened material originally that one can never be certain what really constitutes it. Horný (1957) has recently described *Bojobactrites ammonitans*, a Devonian bactritid with a strongly sculptured shell. In the upper Paleozoic there are again bactritids known with living chambers, as *Ctenobactrites costatus* Shimansky, which has prominent sculpture like that of *Bojobactrites*, and also some smooth shelled forms, notably *Hemibactrites ellipsoidalis*, but there remains a considerable residue of species for which no living chambers are known. Such specimens constitute various species which have been assigned to *Bactrites*, and also the entire Parabactritidae of Shimansky. It is these forms which are so similar to belemnoid phragmocones that they may be belemnoid remains; in this respect, the apparent absence of any real living chambers tends to support the possibility of their belemnoid affinities.

Eobelemnites caneyensis possesses a phragmocone which extends appreciably orad of the anterior limits of the rostrum. Our material of the other Mississippian belemnites fails to show the phragmocones extending beyond the anterior limits of the rostra, but it is necessary to point out that this difference is not necessarily a real one, and may be only the result of the conditions of preservation. Anterior portions of phragmocones which lack the support of a surrounding rostrum are relatively fragile, and face several hazards in preservation not shared by the more solid parts of the shell. First, like the proostraca, they are certainly highly liable to breakage prior to burial of the shell. A good bit of our present material faces still another hazard. Most of it is from shales. Any phragmocone buried in shale encounters the possibility of flattening by compaction. Under such flattening, the solid rostra may retain considerable thickness, but the unsupported phragmocone may be crushed flat. Our material shows, almost without exception, a progressive adoral flattening as the supporting rostrum thins anteriorly around the phragmocone. The specimens thus flattened would preserve the anterior phragmocones only as films and impressions in the shale. Weathering of the shale releases the solid rostra, but the flattened impressions of any phragmocones will not be preserved, and can, indeed, only be found by digging into fairly unweathered shales. Most, perhaps all, of our present material is from weathered shale surfaces, with the exception of the four specimens of the genus *Bactritimimus*. These four specimens, though occurring in limestone, are so fragmentary that quite evidently they were extensively broken and abraded prior to burial. It can, then, be seen that the negative evidence of the absence of phragmocones extending beyond the forward limits of rostra is of as little value as the absence of any recognizable proostraca.

Rostral apices.—The abundant material of *Hematites* poses several problems. The first, and greatest, that of variation within the species, has already been dealt with sufficiently in the specific descriptions. There is, however variation in the tip of the rostrum which requires comment. Some rostra have relatively small pointed tips (pl. 113, figs. 17–28) but others show relatively large extremely blunt apices. Some are pointed and ogivoid in form (Pl. 115, figs. 13–15) and display a cruciform pattern at the apex which is, in general, characteristic of many belemnoids. There are others, however, which show quite different apices. One specimen (Pl. 114, figs. 11–14) shows a

nearly flat apex without cruciform or without even any clear radial markings. Another form (Pl. 114, figs. 5–8) shows on its apex a short blunt rod-like extension, partially covered with radial markings. A third (pl. 114, figs. 1–4) shows a blunt but a more smoothly rounded surface. These last three specimens show variation suggestive of the rostral apices which Müller-Stoll (1936) has considered to be modifications of the rostra after the loss of the epirostra. The epirostrum is a peculiar structure, and even those who have studied it mostly closely are somewhat perplexed as to suggest its function. It has been regarded as a specialization, found in only a few Jurassic genera of the Passaloteuthinae. It would, indeed, be most remarkable to find an epirostrum in belemnites as old as the Mississippian. In spite of the large number of fragments of rostra of *Hematites* in the Chainman shale of Utah, no apical fragment shows the absence of a central radial structure which characterizes a true epirostrum. It is necessary to conclude that these variations in the apex of *Hematites* are due to other causes, possibly either injury and repair, or actual modification by resportion. Curiously, a cross section of *Hematites* taken near the apical end of the phragmocone (Pl. 116, fig. 3) shows outer coarse radial structure which is regarded as typical, but contains also a central region, directly surrounding the phragmocone, in which the structure is vesicular, and is faintly reminiscent of the sections of epirostra figured by Müller-Stoll.

Conotheca.—The failure of our material of *Hematites* to show three good layers in the conotheca is surprising, for such layers are known in younger belemnoids, and there is every reason to believe that they may correspond to the three layers of the shell of *Nautilus*. Perhaps conditions of replacement of original shell materials may play an important role in the appearance of the conotheca in our present material. It seems necessary, however, to note that our conothecae appear significantly thinner than those studied in thin section by Müller-Stoll (1936), and the differences may be real, at least in part.

Protoconch.—The protoconch is generally preserved in younger belemnoids where it appears as an inflated sphaeroidal chamber at the apex of the phragmocone. Hanai (1953) has presented a detailed study of the phragmocone, protoconch and initial stages of the rostrum in *Neohibolites miyakoensis*, showing a rather remarkable structure of short conical layers on the apex of the protonconch, which suggests a septate structure and which he called a *Salterella* stage. The comparison is apt, but as *Salterella* is not, from present evidence, even a cephalopod, no real relationship with that problematical genus should be inferred. The protoconch of Triassic genera has not been studied in detail. Von Bülow (1915) figures a longitudinally split rostrum within which can be seen the exterior of a phragmocone which terminates in a tiny chamber, scarcely larger than the succeeding part of the phragmocone, which he identifies as the protoconch. In two longitudinal sections of *Hematites* the apex of the phragmocone is seen, but neither of them shows a protoconch. One of these sections (Pl. 116, fig. 5) shows apparent crushing of the apex of the phragmocone, but crushing alone seems inadequate to account for the rather abrupt termination of the conothecal wall and the absence of even a crushed remnant of the protoconch. Another section (Pl. 116, fig. 4) shows the apex of a phragmocone in which all structures are poorly defined, and suggest poor calcification. Still another, while not retaining the apex of the phragmocone shows its initial portion to lack septa or even a good conotheca. The sections together suggest the possibility that the protoconch and the earliest part of the phragmocone may have been resorbed as growth progresses for it appears that vicissitudes of preservation alone are inadequate to account for the observed phenomena. Clearly, however, this explanation must be taken as a tentative one and the matter is one on which further observations are eminently desirable.

Phyletic considerations.—The variation in form and structure in Mississippian belemnites is such that there are now four genera required to accommodate the known species. This should be no great surprise, for although no Pennsylvanian Coleoidea are yet known, those of the Permian and Triassic show such diversity of form as can be accounted for only by a previous rather long

geological history of the stock. The Triassic contains a number of Belemnitidae, those genera commonly set apart as the Aulacoceratidae, the undesirability of which family we have already discussed. They may be summarized as follows:

Aulacoceras Hauer has essentially the following characteristics: Rostra are pointed, symmetrical apically, gently expanding for a short distance, then essentially tubular. The surface is marked by longitudinal striae and the flat interspaces between them may bear finer and usually distant and irregular transverse striae. A single lateral pair of furrows is developed. Phragmocones are moderately slender, compressed in section. Little information is available on the sutures, but they appear to be nearly, if not perfectly, straight and transverse. The siphuncle is ventral, the segments slender, essentially tubular, and apparently the septal necks are quite short. The conothecal striae are unknown, but von Bülow (1915 Pl. 57, fig. 4, text-figs. 12,13) has illustrated longitudinal ribs on the surface of the conotheca with finer transverse markings, quite suggestive of the small Ordovician species of *Kionoceras*. Gordon (1957, Pl. 2, figs. 3,4) has figured a *Kionoceras* with very similar surface markings from the Mississippian of Alaska.

Dictyoconites Mojsisovics agrees in general with *Aulacoceras*, but has the striae of the surface closer, and many species show a finely cancellate surface. Some, but probably not all species, have a rostrum the apical part of which is slightly swollen and therefore clavate in form. Conothecal markings are known for several species of this genus, as has been noted above. The phragmocone is compressed in cross section, the ventral siphuncle is slender, and apparently its necks are quite short as in *Aulacoceras*.

Ausseites Flower, 1944, is a name proposed for the adequately preserved specimens which for a long time were called *Atractites*. The genus *Atractites* was unfortunately based upon a worn fragment of a rostrum, so altered by decay that both apical and anterior ends are pointed. Such a form is not properly identifiable specifically or generically, and the identification of unaltered belemnite material with it is necessarily an assumption which cannot be proved. Fischer (1951) is not correct in stating that *Atractites* was abandoned because forms with both short and long rostra had been assigned to it, and it was not evident to which group its genotype, *A. alpinus*, belonged. The question never arose. Obviously, only a belemnoid with a rather long rostrum could produce the type of object which Gümbel described, and which must have been very much like the specimen which Mojsisovics figures on supplement pl. 2 of his later (1902) paper. However, it is not demonstrable that such an object can be identified with the adequately preserved species for which *Ausseites* was proposed, to the exclusion of other belemnoid genera with rostra of appreciable size and length.

As it stands, *Ausseites* is a rather variable genus, but is characterized by a smooth rostrum. The known phragmocones may attain considerable size, are compressed in section, and their sutures tend to slope slightly forward from venter to dorsum (see Mojsisovics, 1882–1902, p. 193, fig. 5) and thus shows a slope of the sutures characteristically developed in the older *Eobelemnites*, but in *Ausseites* the septa are typically considerably more distant and the sutures are faintly sinuate. The siphuncles show differences which suggest that as at present deliminted, *Ausseites* is still rather broadly defined, and further study may indicate the desirability of restricting it. Typical *Ausseites* has septal necks which are relatively short, extremely short and sharply recurved dorsally, slightly longer and faintly sinuate in vertical profile ventrally (Mojsisovics, 1882–1902, suppl. Pls. 13 and 15). However, *Atractites convergens* (Hauer) (see Mojsisovics, 1882–1902, suppl. Pl. 16, fig. 1a) has septal necks which are extremely long, extending three fourths to two thirds the length of a camera. As seen in horizontal longitudinal section, they are divergent slightly basally, subparallel apically, and resemble the septal necks seen in the Mississippian genera *Eobelemnites*, *Paleoconus* and *Bactritimimus*, and also the necks of the Parabactritidae.

Metabelemnites Flower, 1944, has an extremely short rostrum. It may well be a forerunner of the genus *Diplopelus* (=*Diplocoelus* Zittel, not Haeckel), a genus currently referred to the Belemnoteuthidae

(Roger, 1952). However, this genus is not typical of the Belemnoteuthidae, having, for that family, an extremely thick rostrum. Other Belemnoteuthidae have been recorded from the Triassic, notably *Phragmoteuthis* Mojsisovics, 1882, which is typical of the family in the suppression of the rostrum to extremely small size and thickness, development of a phragmocone and a large characteristic anterior proostracum of three lobes. There remains to be noted one other Triassic coleoid, a form which Rüger (1942) described as *Belemnoteuthis* sp.?, but which shows some features so bizarre that if it has been interpreted correctly, should have at least a family to itself. It has a simple phragmocone enclosed in a rostrum which is broadly clavate, extremely blunt apically, the dorsal side has transverse zigzag markings, the venter a chevron-shaped region with a granular surface which is framed in a rather elaborate border.

These are the main types of the better known Triassic Belemnitidae. Fischer (1951) has presented a partial analysis of these and of other lesser known genera. His genus *Choanoteuthis* described in the same work is differentiated by supposedly holochoantic septal necks. It is known only from a fragment, and little is known of the rostrum except that its texture is apparently like that of the younger belemnites rather than *Aulacoceras*, and its surface is reported as smooth. The phragmocone is subcircular, centrally located in the rostrum. Its surface has not been observed, but apparently sutures are transverse or nearly so.

All of these genera, together with the lesser known *Zugmontites* and *Calliconites* have quite long rostra and are of the general aspect of the Belemnitidae.

The Permian record consists of only two known species, but one is an apparently typical member of the Belemnitidae, and of the Triassic genus *Dictyoconites*, *D. groenlandicus* Fischer (1947, 1951) but the other (Rosenkrantz, 1946) is a belemniteuthid, *Permoteuthis groenlandica*. In view of the differentiation of Belemnoteuthidae and Belemnitidae in the Permian, as well as the Triassic it is quite obvious that the Coleoidea must have originated considerably earlier for them to produce such marked differentiation.

Our Mississippian forms show considerable variation in the texture of the rostrum, shape of its tip, features of the phragmocone, which varies from circular to strongly compressed, sutures, which may slope forward on either dorsum or venter or may be transverse, may range from straight to rather strongly sinuate, and may or may not have a ventral lobe. The siphuncles may have relatively short necks, recurved dorsally as in *Aulacoceras* and typical *Ausseites*, or they may be extremely long, as in the Parabactritidae. In surveying them it is evident that here the variation in form and structure is less than in the Permian or Triassic, but is still appreciable. In view of these known forms, the single report of a Devonian belemnoid by de Koninck (1843) becomes not only credible, but eminently logical, even though no subsequent finds have as yet confirmed his report. The specimen which he figured is the apical part of the rostrum resembling those of our present genus *Hematites*.

REFERENCES

DAVITASHVILI, L. S., 1949, Kurs paleontogii: Gosgeolizdat moskva, p. 1–834.

FISCHER, A. G., 1947, A belemnoid from the late Permian of Greenland: Meddel. om Grønland, Bd. 133, no. 5, p. 1–24, 2 pls.

——, 1951, A new belemnoid from the Triassic of Nevada: Am. Jour. Sci., v. 249, p. 385–393, pls. 1,2, 1 fig.

FLOWER, R. H., 1939, Study of the Pseudorthoceratidae: Paleontographica Americana, v. 2, no. 10, 214 p., 9 pls., 22 text-figs.

——, 1944, *Atracites* and related coleoid cephalopods: Am. Midland Naturalist, v. 32, no. 3, p. 757–770, 1 pl.

——, 1945, A belemnite from a Mississippian boulder of the Caney shale: Jour. Paleontology, v. 19, p. 490–503, pl. 65, 1 text-fig.

GORDON, M., JR., 1957, Mississippian cephalopods of northern and eastern Alaska: U. S. Geol. Survey Prof. Paper 283, 61 p., 6 pls., 26 text-figs.

HANAI, T., 1953, Lower Cretaceous belemnites from Miyako district, Japan: Japanese Jour. Geology and Geography, v. 23, p. 63–80, pls. 5–7.

HORNÝ, R., 1957, *Bojobactrites ammonitans* n. g., n. sp., (Bactritoidea) ze Stredoceskeho devonu. (*Bojobactrites ammonitans* n. g., n. sp. (Bactritoidea) from the Devonian of central Bohemia): Shorník Ústředního Ústavu Geologického, v. 23, oddíl Paleontologicky p. 285–305, pl. 13.

DE KONINCK, L., 1843, Notice sur un coquille fossile des Terrains anciens de Belgique: Acad. royale sci. Belgique Bull., v. 10, p. 207, 208, 1 pl.

MOJSISOVICS VON MOJSŬAR, E., 1873, Das Gebirge um Hallstatt, 1 theil: Die Molluskenfaunen der Zlambach- und Hallstätterschichten. K. K. Geol. Reichsanstalt. Abb., v. 6, 82 p., 32 pls.

——, 1873–1902, Das Gebirge um Hallstatt: I. Abth., Die Cephalopoden der Hallstätter Kalke: K. K. Geol. Reichsanstalt, Abb., v. 6, p. 1–82, pls. 1–32, 1873; p. 83–174, pls. 33–70, 1875; p. 175–356, suppl. pls. 1–23, 1902.

MÜLLER-STOLL, H., 1936, Beitrage zur Anatomie der Belemnoidea: Nova Acta Leopoldiana, Neue Folge, v. 4, no. 20, p. 157–226, pls. 56–69.

NAEF, A., 1922, Die fossilen Tintenfische: 322 p., 100 text-figs., Jena, Gustav Fischer.

ROGER, J., 1952, Sous-classe des Dibranchiata, *in* Privateau, J., Traité de Paleontologie, v. 2, p. 689–755, text-figs. 1–102, Paris, Masson et Cie.

ROSENKRANTZ, A., 1946, Krogbarnende Cephalopoden fra Østgrønlands Perm: Medd. Dansk Geol. Foren., v. 11, no. 1, p. 160,161, text-figs. 1–4.

RÜGER, L., 1942, Ein Dibranchiatenfund aus dem oberen Muschelkalk von Gelmerode (Thuringen): Jenaische Zeitschr. Medicin Naturw., v. 75, p. 179–196, 8 text-figs.

SHIMANSKY, V. N., 1954, Priamye nautiloidei i baktritoidei Sakmarskogo i Artinskogo Iarusov Iuzhnogo Urala: Akad. Nauk, SSSR, v. 44, 154 p., 12 pls.

TEICHERT, C., 1933, Der Bau der actinoceroiden Cephalopoden: Palaeontographica, v. 78, Abt. A, p. 111–230, pls. 8–15, 50 text-figs.

VON BÜLOW, E. U., 1915, Orthoceren und belemnitiden der Trias von Timor: Paleontologie von Timor, Lief. 5, no. 7, p. 1–72, pls. 57–72.

——, 1915, Die Aulacoceratidae der oberen Trias von Timor: 28 p., pls. 1,2(57,58) Berlin. (Reprint or preprint of part of the preceding.)

VON MOJSISOVICS—(see Mojsisovics von Mojsuar).

YOUNGQUIST, W., 1949, The cephalopod fauna of the White Pine shale of Nevada: Jour. Paleontology, v. 23, p. 276–305, pls. 56–64, 3 text-figs.

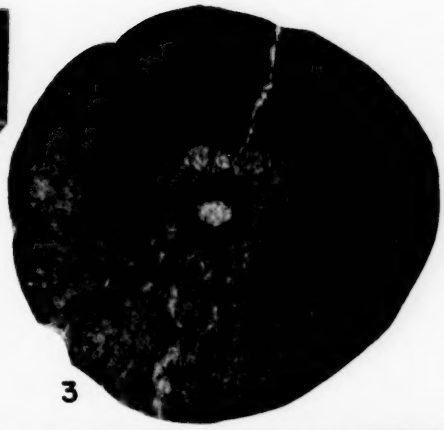
MANUSCRIPT RECEIVED JANUARY 6, 1959.

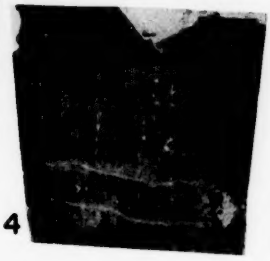
EXPLANATION OF PLATE 116

FIGS. *1–7*—*Hematites barbarae* Flower & Gordon. Paratypes, USNM 120025A–E, thin sections showing structure. *1*, longitudinal section (A) passing through center of a rostrum ×4; note absence of a median element, and longitudinal fibrous appearance. *2*, sagittal section (B) ×4, through phragmocone, showing siphuncle on left, with apical portion apparently poorly calcified. *3*, cross section (C) through rostrum, with portion near apex of phragmocone at center. *4*, section of a fragment (D), orientation uncertain, but showing apex of phragmocone poorly calcified and most imperfectly preserved, ×5. *5*, portion of section (E) ×8. showing the apical end of a phragmocone in sagittal section, venter and siphuncle at right. Crushing has occurred, but seems inadequate to account for absence of a protoconch. *6*, enlargement of an anterior part of the same section (E), showing a recurved dorsal septal neck, extremely thin conotheca and part of the rostrum, ×18. *7*, anterior end of section (B) shown in fig. 2, ×10, showing siphuncle segments in greater detail. All from the Chainman shale, Burbank Hills, Utah.

1

2


3

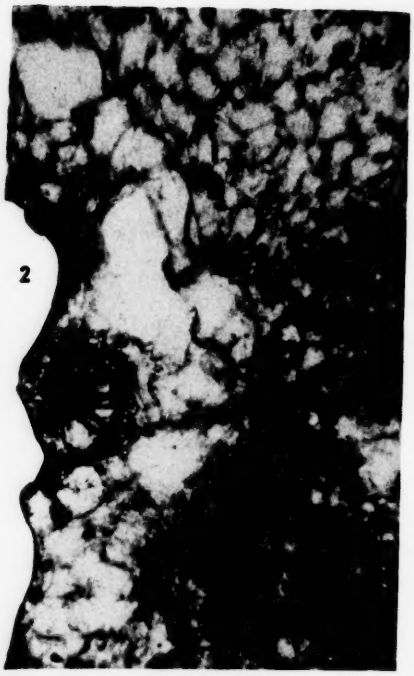

4

6

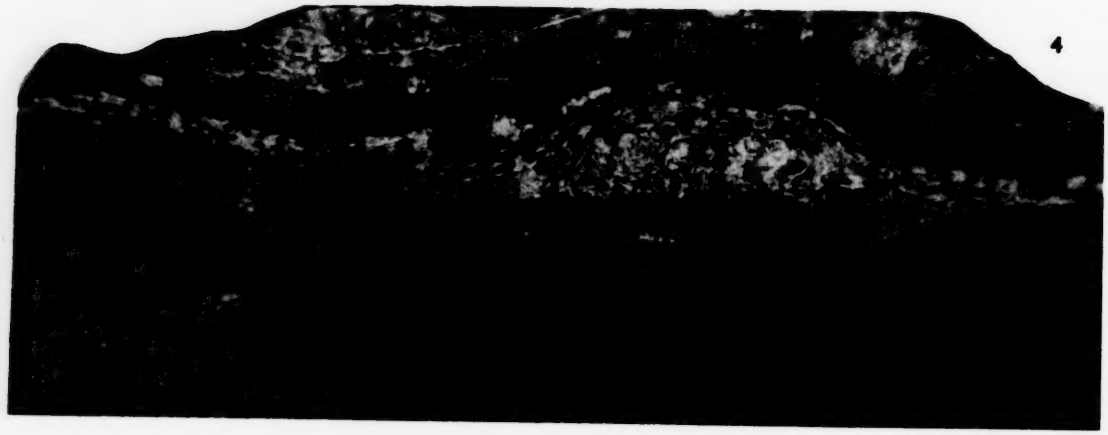
5

7

1


2

3


4

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 843–845, PL. 117, SEPTEMBER, 1959

OCCURRENCE OF THE FORAMINIFERAL SPECIES, *ACERVULINA LINEARIS* HANZAWA FROM ST. BARTHOLOMEW I., FRENCH WEST INDIES

SHOSHIRO HANZAWA
Tohoku University, Sendai, Japan

ABSTRACT—*Acervulina linearis*, an encrusting Foraminifera, known previously from the upper Eocene of the Indo-Pacific region, was found in middle Eocene limestones of St. Bartholomew, French West Indies. These specimens are described and illustrated.

INTRODUCTION

THE encrusting Foraminifera, *Acervulina linearis* Hanzawa (1947, p. 60,61, pl. 16, figs. 2–5) which was known previously only from the upper Eocene (Tertiary *b*) of the Indo-Pacific region was found in thin sections made from middle Eocene limestone from St. Bartholomew, French West Indies. As this occurrence extends the geographic and stratigraphic ranges of this sessile Foraminifera, the West Indian specimens are described and compared with the type from New Britain (Hanzawa, *loc. cit.*).

This species was known previously from the Matansa limestone of Saipan and Rota Islands, Mariana Islands; the Aimilik limestone of Babelthuap Island, Palau Islands; the Miyara formation of Ishigaki-jima, South Ryukyu Islands (Hanzawa, 1957, p. 68, pl. 24, figs 1a–c; pl. 29) and from New Britain (Hanzawa, 1947, *loc. cit.*) all of which are dated as upper Eocene (Tertiary *b*). At these localities it is associated with other species of larger Foraminifera, such as, *Fabiania cassis* (Oppenheim), *Biplanispira mirabilis* (Umbgrove), *B. hoffmeisteri* (Whipple), *Pellatispira* spp., *Discocyclina* spp., *Asterocyclina* spp., and *Nummulites* spp., all characteristic of the upper Eocene of the Indo-Pacific region. It has never been found in any strata of other geologic age.

At St. Bartholomew *A. linearis* is associated with numerous species of larger Foraminifera, many of which were listed by Cole (1958a, p. 192). Vaughan (1932, p. 97) placed these limestone in the middle Eocene, an assignment with which Cole (*loc. cit.*) agreed. The species which accompany *A. linearis* follow:

Loc. SB. 18
- *Amphistegina parvula* (Cushman)
- *Asterocyclina habanensis* Cole and Bermudez
- *A. aster* (Woodring) (Cole, 1958b) [originally *A. penonensis* Cole and Gravell]
- *Ferayina coralliformis* Frizzell
- *Nummulites guayabalensis* Barker
- *Operculinoides floridensis* (Heilprin)
- *Pseudophragmina* (*Proporocyclina*) *flintensis* (Cushman) (Cole, 1958b) [originally *P.* (*P.*) *cushmani* (Vaughan) and *P.* (*P.*) *psila* (Woodring)]

Loc. SB. 19
- *Amphistegina parvula* (Cushman)
- *Asterocyclina habanensis* Cole and Bermudez
- *A. monticellensis* Cole and Ponton

EXPLANATION OF PLATE 117

(All figures ×80)

FIGS. *1,2*—Horizontal sections which show juvenaria (*Cibicides*-like structures found near the center of Fig. *1* and left-center of Fig. *2* and chambers of the ephebic stage. The darker area of Fig. *2* (lower-right) is a calcareous alga. Fig. *1*-Loc. SB. 18; Fig. *2*-Loc. SB. 27.

3—Vertical section of a specimen completely surrounding a thallon of a calcareous alga (dark central area). The brighter, linearly disposed, delicate lines are the roofs and floors of the chambers. Some discontinuities in the brighter lines are delicate perforations of the roofs and floors of the test. Loc. SB. 19.

4—Vertical sections (lighter area) interwoven with thallons of a calcareous alga (darker areas). Loc. SB. 44.

	Width of chambers, μ	Height of chambers, μ	Roofs and floors, thickness, μ
I	37–62 sometimes up to 211	11–30	5
II	34× 85 sometimes up to 170×200	15–32	5–10

	Septa, thickness, μ	Pores in roofs and floors, diameter, μ
I	5–11	5
II	5–11	5

A. aster (Woodring) (Cole, 1958b) [originally *A. penonensis* Cole and Gravell]
Discocyclina (*Discocyclina*) *marginata* Cushman
Eoconuloides wellsi Cole and Bermudez
Fabiana cassis (Oppenheim) [originally *Fabiania cubensis* (Cushman and Bermudez)]
Helicostegina gyralis Barker and Grimsdale
Lepidocyclina (*Polylepidina*) *antillea* Cushman
Nummulites guayabalensis Barker
Operculinoides floridensis (Heilprin)
Pseudophragmina (*Proporocyclina*) *flintensis* (Cushman) (Cole, 1958b) [originally *P.* (*P.*) *convexicamerata* Cole and Gravell and *P.* (*P.*) *cushmani* (Vaughan)]
P. (*P.*) *teres* Cole and Gravell

Loc. SB. 22
Asterocyclina habanensis Cole and Bermudez
A. aster (Woodring) (Cole, 1958b) [originally *A. penonensis* Cole and Gravell)]
Cymbaropora irregularis Keijzer
Lepidocyclina (*Polylepidina*) *antillea* (Cushman)
Operculinoides floridensis (Heilprin)
Pseudophragmina (*Proporocyclina*) *teres* Cole and Gravell

ACKNOWLEDGMENTS

The writer is indebted to Professor W. Storrs Cole who supplied the thin sections and gave permission to publish on the material which was collected by the late Dr. Alfred Senn. The study was made in connection with an examination of various larger Foraminifera in the Cole collection at Cornell University as a part of the writer's program in the United States as a Fulbright Exchange Visitor during the academic year 1958–1959. Mr. K. Norman Sachs, Jr. kindly aided in preparing the photomicrographs.

LOCALITIES IN ST. BARTHOLOMEW AT WHICH *A. linearis* OCCURRED

SB. 3. Section on the Northeast ridge of the small rocky island of "Pain de Sucre," West of Gustavia.

Approx. 22 m of coarse-bedded, massive *Lithothamnium*-, Hydrocoral- and foraminiferal limestone with *Nummulites*, *Discocyclina*, *Asterocyclina Lepidocyclina* and the rare corals and echinoids.

SB. 3. from the middle of the formation. Probably Upper limestone of the St. Batholomew formation (resting with a glauconitic, sandy and conglomeratic base directly on igneous rock.

SB. 8. Section at the promontory separating Anse des Lézards and Anse des Cayes, on the North coast of the island.

Approx. 45 m alternation of coarse-bedded, massive *Lithothamnium*- and foraminiferal limestones and two bands of cross-bedded, conglomeratic volcanic tuffs.

SB. 8. Gray *Lithothamnium*- and foraminiferal limestones with *Nummulites*, *Discocyclina*, *Lepidocyclina* (N.W. end of promontory).

Lower limestones of St. Bartholomew formation.

SB. 18, 19. Section at the northern slope of the promontory separating Anse des Cayes and Baie de St. Jean.

SB. 18 (Directly on top of the vertical limestone cliff): 1 m compact *Lithothamnium*- and foraminiferal limestone (*Discocyclina* and *Asterocyclina*).

SB. 19. (Directly overlying SB. 18): coarse-bedded glauconitic foraminiferal limestone (*Nummulites*, *Discocyclina* and *Asterocyclina*).

Upper limestone of St. Bartholomew formation.

SB. 37. Section along the western side of "Anse du Gouverneur" towards Pointe du Nègre.

SB. 37: First limestone outcrop on the west side of Anse du Gouverneur, at 19 m and 21.5 m above sea level.

Coarse-bedded, massive *Lithothamnium* limestone with inclusions of black chert and with *Nummulites*, *Lepidocyclina* and *Dictyoconus*.

Lower limestone of St. Bartholomew formation.

SB. 44. Path from Coporal to Colombier, at main watershed near the school "Alcide Terrac 1923"

Coarse- to well-bedded fine-grained glauconitic limestones with *Nummulites*, *Discocyclina* and *Asterocyclina*.

Upper limestone of St. Bartholomew formation.

DESCRIPTION OF SPECIES

Family PLANORBULINIDAE

Genus ACERVULINA Schultze, 1854

ACERVULINA LINEARIS Hanzawa

Pl. 117, figs. 1–4

Acervulina linearis Hanzawa. Hanzawa, 1947, p. 60,61, pl. 16, figs. 2–5; 1957, p. 68, pl. 24, figs. 1a–c; pl. 29.

As the specimens occurred in indurated limestones, it was possible to study them only by means of thin section. However, the internal structure of these specimens is identical with that of the specimens from New Britain and Micronesia. Moreover, the measurements made of the internal features are the same as those obtained from the Indo-Pacific specimens.

Although the embryonic apparatus was not observed previously, two of the thin sections used in this study show this feature. The juvenarium of this species is entirely different from the ephebic part of the test. In median section it resembles *Cibicides* (figs. 1,2, pl. 117) and contrasts markedly from the ephebic part of the test which in median section consists of polygonal or irregular chambers bounded by straight or sinuous walls. These chambers are not only irregular, but also vary in size.

The *Cibicides*-like embryonic apparatus, about 300 μ in diameter, has $1\frac{1}{2}$ volutions and a total of 10 chambers. Five of these chambers comprise the first volution.

The table which follows gives a comparison of significant internal measurements of the St. Bartholomew specimens (II) and the form from the Mariana Islands (I).

REFERENCES CITED

COLE, W. S., 1958a, Names of and variation in certain American larger Foraminifer—no. 1. Bull. Am. Paleontology, v. 38, no. 170, 179–213, pls. 18–25.

——, 1958b, Names of and variation in certain American larger Foraminifera, particularly the discocyclinids—no. 3. *Ibid.*, no. 176, p. 411–429, pls. 50–53.

HANZAWA, S., 1947, Note on an Eocene foraminiferal limestone from New Britain, Jap. Jour. Geology Geography, v. 20, nos. 2–4, p. 59–61, pls. 14,15.

——, 1957, Cenozoic Foraminifera of Micronesia. Geol. Soc. America, Mem. 66, p. 1–163, pls. 1–38, text-figs. 1–12, 3 maps, 5 tables.

VAUGHAN, T. W., 1932, American species of the genus *Dictyoconus*. Jour. Paleontology, v. 6, no. 1, p. 94–99, pl. 14.

MANUSCRIPT RECEIVED DECEMBER 22, 1958.

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 846–848, PL. 118, 2 TEXT-FIGS., SEPTEMBER, 1959

A METHOD FOR RAPID SORTING OF FORAMINIFERA FROM MARINE PLANKTON SAMPLES*

ALLAN W. H. BÉ
Lamont Geological Observatory, Columbia University, Palisades, New York

ABSTRACT—A method is described for the rapid removal of planktonic Foraminifera and other shelled organisms from marine plankton samples. Saturated sodium chloride solution (sp. gr. 1.20) is utilized for the density separation of the shelled plankton (sp. gr. 1.40) on the one hand and the non-shelled plankton (sp. gr. 1.09) on the other. The percentage of recovery of planktonic Foraminifera by weight and by number of specimens for ten plankton samples average 93 and 79 percent, respectively.

INTRODUCTION

A PLANKTON sample consists of a heterogeneous population of organisms gathered from seawater by net tow, filtration or centrifugation. Plankton investigators interested in specific taxonomic groups are aware of the tedious and time-consuming labor involved in sorting individual microscopic specimens from the bulk of a sample. Hours or days may be spent to remove specimens of a taxonomic group from a single sample. Devices for accelerating microscopic examination include plankton splitters, counting chambers and the like, designed for statistical estimation of total abundances from the bulk sample. These methods are generally unsatisfactory because estimation (i.e., taking a sample of a sample) further reduces the reliability of determining the population parameter in nature. Mechanical separation of selective groups of plankton organisms is hampered by the fact that the majority have overlapping ranges in size, shape and specific gravity.

These difficulties are, to a certain extent, alleviated for the student of planktonic Foraminifera, Radiolaria, Pteropoda and other organisms possessing calcareous or siliceous shells. Such organisms have a greater specific gravity (about 1.40) than the majority of plankton and this property may be utilized to separate them from other plankton organisms (copepods, dinoflagellates, chaetognaths, euphausiids, etc.).

In the following discussion, an effective and inexpensive procedure is outlined for the rapid removal of Foraminifera from plankton samples.

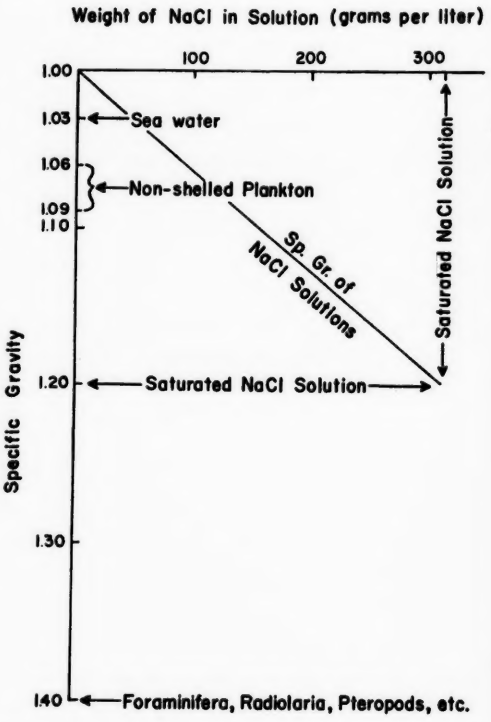
* Lamont Geological Observatory Contribution No. 364, Biology No. 25.

This project is an outgrowth of more detailed studies on the ecology of planktonic Foraminifera at Lamont Geological Observatory. It is made possible through Rockefeller Foundation grants in marine biology (RF 54087 and RK 57076). The writer wishes to thank Mr. Lawrence Linton for his assistance during this project.

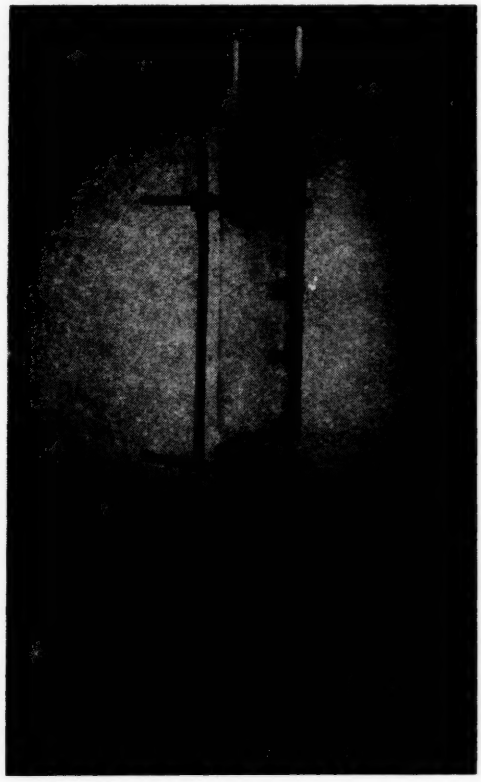
MATERIALS AND METHODS

The difference in specific gravity between the shelled and non-shelled plankton organisms is the physical basis of the separation process. A saturated solution of sodium chloride is employed as the liquid medium in which the density separation takes place. The specific gravities of sea water, saturated sodium chloride solution, shelled and non-shelled plankton are shown in text-figure 1. The following procedure and apparatus (text-fig. 2) are used in the separation process:

1. An acrillic plastic burette (12 cm. diameter, 63 cm. high) is filled with 6000 ml. saturated sodium chloride solution (310 grams NaCl per liter of distilled water), having a specific gravity of 1.20.
2. The preservative (buffered formalin) of the sample is drawn off to prevent dilution of the saturated sodium chloride solution.
3. The sample is poured into the burette. Only a thin layer of plankton should cover the upper part of the column of sodium chloride solution. Some agitation facilitates the sinking of the Foraminifera, etc. and disentangles them to some extent from the lighter plankton assemblage. Separation of the lighter and heavier portions begins immediately. After about three to four minutes, while the majority of the plankton remains floating, a large portion of the shelled organisms has settled to the bottom.
4. The Foraminifera and other shelled organisms are drained through the stopcock.
5. The drainings are repeated several times



TEXT-FIG. *1*—Comparison of specific gravities of sea water, non-shelled plankton, saturated NaCl solution and shelled plankton.



TEXT-FIG. *2*—Apparatus showing burette filled with saturated sodium chloride solution. Note the dark band of plankton suspended in the upper portion of the column.

until the number of shelled organisms in the burette becomes negligible. In time the non-shelled plankton sinks and obscures any remaining Foraminifera. However, with each draining (in a 500 ml. beaker) a large number of air bubbles are produced which serve to buoy the plankters while allowing the shelled organisms to settle—thus repeating the separation process on a smaller scale. The floating two-thirds portion in the beaker is poured back into the burette.

The number of drainings depends upon the size of the plankton sample and the concentration of the Foraminifera. For plankton samples with about 30 ml. displacement volume and containing several hundred Foraminifera, it may take about 10–20 drainings in about 30–45 minutes. The decision when to stop draining rests upon individual discretion. Eventually the number of shelled organisms becomes insignificant in relation to the rest of the plankton. Complete recovery of all shelled organisms is not possible because a number of individuals always remains entangled in the main body of plankton. Frequent agitation remedies this problem to some extent.

6. Both the floating and settled portions are preserved again in buffered formalin.

RESULTS

The advantage of this method is in the rapidity and ease in which the great majority of the Foraminifera in a plankton sample can be concentrated. Henceforth, it is possible to neglect the "slag" of plankton, while using only the separated portion for studying the standing crop and species composition of planktonic Foraminifera. Investigators particularly interested in some aspects of study of these shelled organisms —e.g. chemistry, mineralogy, morphology, or total biomass of the foraminiferal shells— where a large quantity of organisms is essential, should find this separation method useful.

The effective recovery of Foraminifera from a single plankton sample by the separation process is illustrated in Pl. 118 (Fig. 1–4). A random view of an unprocessed plankton sample (Fig. 1) shows the small number

TABLE 1.—EFFECTIVENESS OF RECOVERY OF PLANKTONIC FORAMINIFERA FROM TEN PLANKTON SAMPLES

	Sample No.	Locality		Depth range of sample (m)	Total number of Foraminifera in sample	No. of Foraminifera recovered by separation process	Recovery percentage by no. of specimens (%)	Total weight of Foraminifera in sample (mg)	Weight of Foraminifera recovered (mg)	Recovery percentage by weight (%)
		Lat. N	Long. W							
1	V14-1D	38-03	70-48	0–300	2,560	2,440	95	19.1	18.1	95
2	V14-2D	37-24	69-06	0–315	2,530	2,390	94	22.9	21.8	95
3	V14-6D	34-55	65-58	0–300	1,120	900	80	7.7	7.1	92
4	V14-24D	10-16	32-08	0–300	2,420	2,115	88	11.9	11.1	93
5	V8-18	14-46	18-09	0–365	830	660	80	31.0	29.9	96
6	V8-29	19-47	80-41	0–1,370	2,750	1,610	59	9.2	7.8	85
7	V8-34	19-14	76-51	0–670	2,050	1,550	76	11.4	10.6	93
8	V8-35	19-38	76-18	0–690	1,610	1,340	83	8.7	7.7	89
9	V8-37	18-24	75-11	0–385	830	590	71	3.9	3.8	97
10	V8-41	19-11	67-06	0–400	1,780	1,230	69	12.6	11.7	93

of Foraminifera present among the myriad of plankton. The rich concentration of shelled organisms (Fig. 2) is obtained from the same plankton sample through the salinity separation process. A certain amount of non-shelled plankton is unavoidably present in the settled portion. The contrast between the large number of planktonic Foraminifera removed from the settled portion (Fig. 3) and those few retained in the bulk of plankton after processing (Fig. 4) is clearly evident.

The percentage of Foraminifera by number of specimens or by weight recovered from ten plankton samples was consistently high (Table 1). The recovery percentage by number of foraminiferal specimens varied from 59 to 95 percent, averaging about 79 percent; whereas the recovery percentage by weight of the specimens varied from 85 to 97 percent, averaging about 93 percent. In every sample, it is evident that recovery by number of specimens is smaller than by weight. This can be attributed to the larger number of juvenile, often thin-shelled and spinose, specimens in the samples with relatively small numerical recovery (samples 6, 9, and 10 in Table 1). These juveniles, belonging to the species *Globigerinoides rubra*, *G. sacculifera*, *G. conglobata*, and *Globigerinella aequilateralis*, are smaller than the mesh diameter (200 microns) of the plankton net, and, theoretically, should have passed through the net. Consequently, disregarding these juvenile specimens should not impede the study of absolute and relative abundances of the Foraminifera *normally* retained within a plankton-net tow (i.e. those larger than 200 microns).

The less variable and high recovery percentages by weight (see Table 1) indicate that regardless of the number of juveniles retained in the floating bulk of plankton, the majority of the larger and heavier foraminiferal specimens is recovered by the salinity separation process. The weight of the calcareous foraminiferal tests can be used to determine (a) the amount of calcium carbonate that is extracted by planktonic Foraminifera from various oceanic areas, and, (b) the rate and amount of deposition of the foraminiferal tests on the present ocean bottom. Such knowledge of living populations could serve as standards of comparisons in paleoecological interpretations of fossil globigerina oozes.

MANUSCRIPT RECEIVED JANUARY 17, 1959

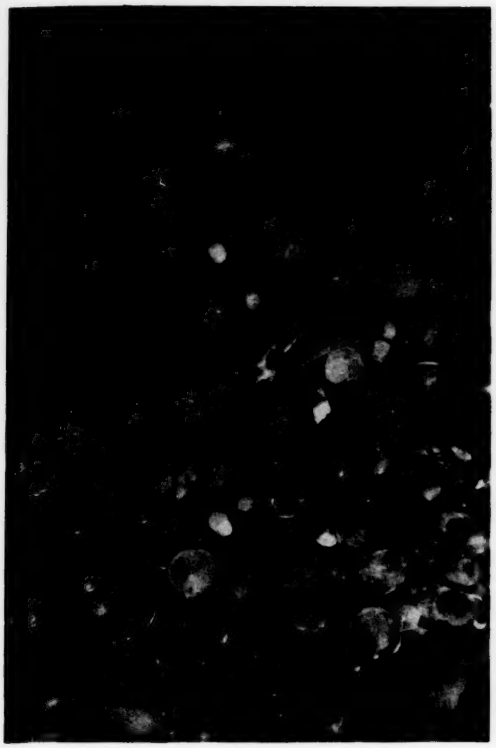
EXPLANATION OF PLATE 118

FIG. *1*—Plankton sample before processing. Note planktonic Foraminifera (black circles) amid the non-shelled organisms. Figures *1*,*2*,*3*, and *4* are of the same sample. ×10.

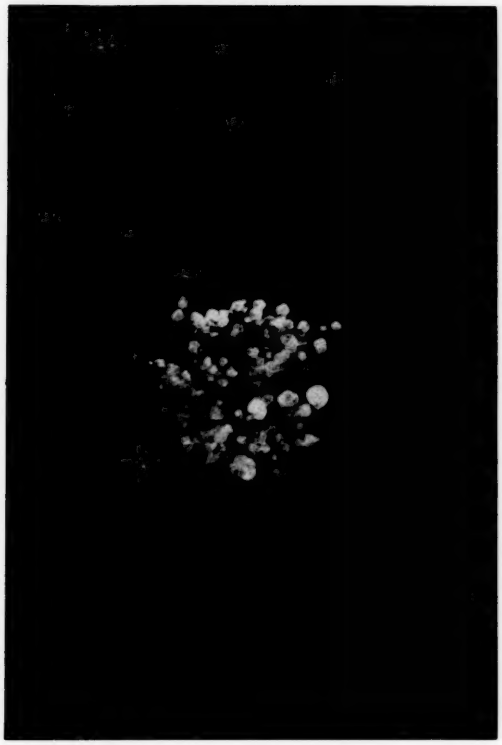
2—The settled portion of the plankton sample after processing, showing primarily shelled organisms (Foraminifera, Pteropoda, and Heteropoda). ×10.

3—Planktonic Foraminifera that were recovered by the salinity separation process. ×7.

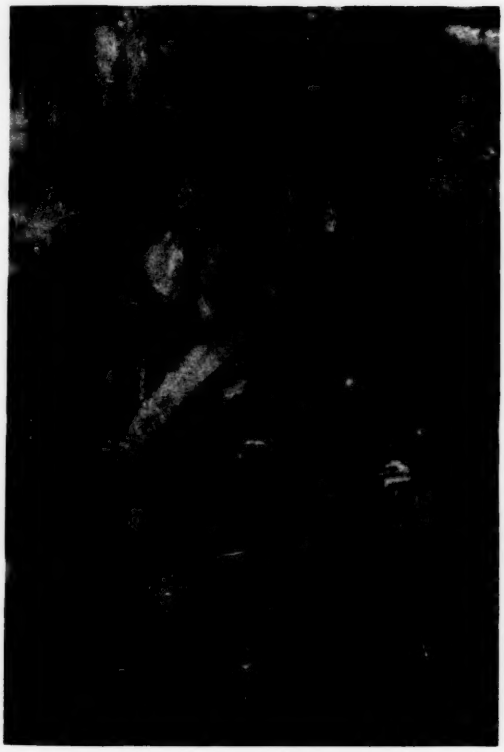
4—Planktonic Foraminifera that were retained in the bulk of plankton after processing. They represent about 5% of the total planktonic Foraminifera. ×7.



2



4



1

3

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 849–852, PL. 119, 4 TEXT-FIGS., SEPTEMBER, 1959

A NEW FOSSIL STINGLESS BEE (MELIPONINI) FROM THE AMBER OF CHIAPAS, MEXICO[1]

ALVARO WILLE
Department of Entomology, University of Kansas, Lawrence, Kansas

ABSTRACT—A new fossil stingless bee, *Trigona* (*Nogueirapis*) *silacea* closely related to the living *T. butteli* Friese, is described from Middle Miocene and possible Middle Miocene amber of Chiapas, Mexico.

THE specimens on which the following description is based are preserved in amber obtained by the University of California from two different localities in the vicinity of Simojovel, Chiapas, Mexico (see Hurd and Smith, 1957; Roth, 1958).

One of the most interesting facts about this new fossil stingless bee is its close similarity to the recent *Trigona*. Pe. Jesús S. Moure, who had the opportunity to examine some of the specimens, expressed the opinion to the author that they were close to *Nogueirapis*. *Nogueirapis* was erected by Moure (1953) as a subgenus of *Partomona* to include the species described by Friese as *Trigona butteli*[2] (a rare species from Peru, Bolivia, the upper Amazon and Territory of Rio Negro). Subsequent study of the fossils showed that Moure's beliefs were well founded. The similarity of the fossils with *T. butteli* is so close that the writer believes it is possible that *T. butteli* is a direct descendant. Not only are they morphologically very similar, but also the color and general distribution of the dark areas are almost identical. The main differences are details of wing venation, inner surface of hind tibia and size (the fossil 3 mm., *T. butteli* 4.5 to 5 mm.).

In 1896 Tosi described two species of fossil bees, *Meliponorytes succini* and *M. sicula*, from the Sicilian amber (Middle Miocene), which could be assigned clearly to the Meliponini. In spite of the fact that *Meliponorytes* shares many characters with recent stingless bees, it is set apart from them by the possession of two denticles (sulci) on the outer half of the apex of the mandible, and, as Schwarz (1948) has already pointed out, by the apparent lack of a comb or pecten at the apex of the hind tibia. This comb is typical of the Meliponini, with the exception of the four species of *Lestrimelitta*.

The author is at present engaged in a complete revision of the genera and subgenera of the stingless bees of the world, and hopes to offer some solution to the controversy on the systematics of this group. In the meantime, this species is placed here in the genus *Trigona* (s.l.), subgenus *Nogueirapis*.

TRIGONA (NOGUEIRAPIS) SILACEA,[3] n. sp.
Pl. 119

Length 3 mm. General color ocher, the following parts dark: large area on upper part of head, covering vertex, extending anteriorly to level above antennal sockets, where dark area is medially notched around frontal line, at sides curved gently upwards leaving narrow ocher paraocular area, on genal area extending to same level as anteriorly (text-fig. 1 and 2); dorsal surface of flagellum; distal margin of mandible and narrow strip at base; malar area; scutellum; metanotum; distal border of each abdom-

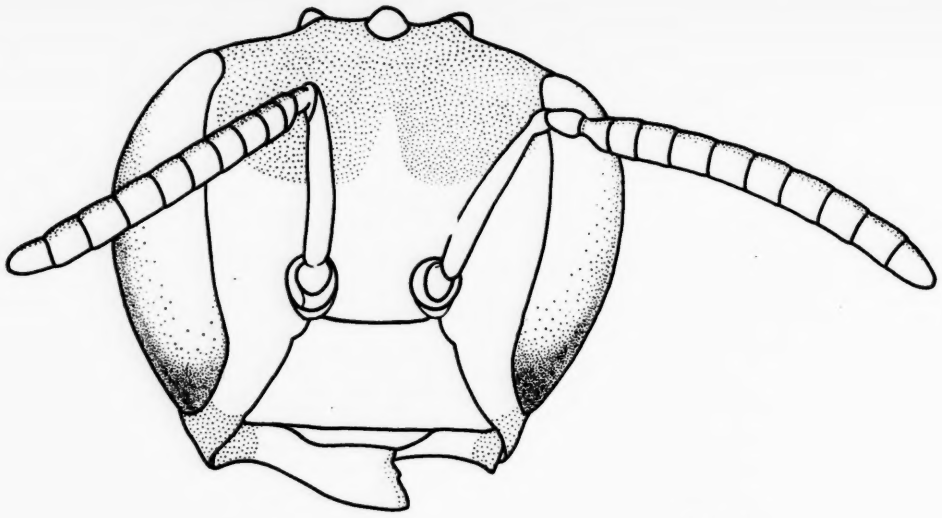
[1] Contribution No. 1027 from the Department of Entomology of the University of Kansas.

[2] Since this paper was written Pe. Jesús S. Moure examined specimens of *Trigona mirandula* Cockerell from Costa Rica. He tells me that this species is a *Nogueirapis*, also very similar to the fossil form.

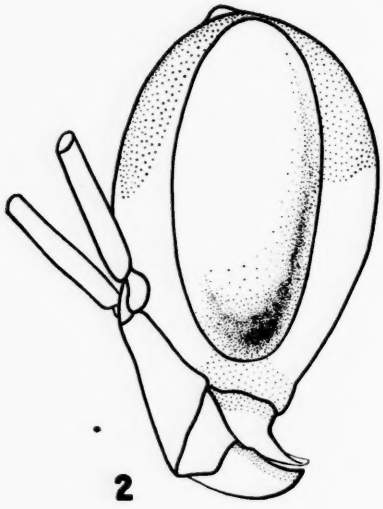
[3] From the Latin *silaceus:* ocher.

EXPLANATION OF PLATE 119

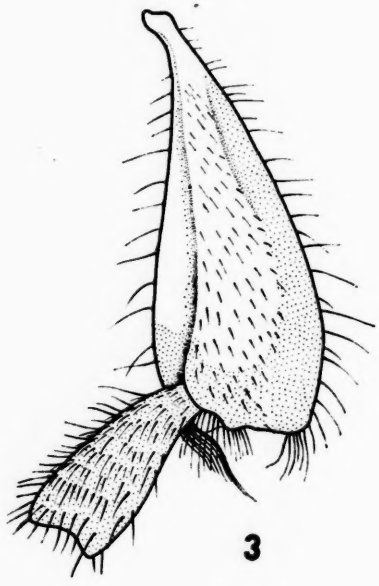
Trigona (*Nogueirapis*) *silacea*, n. sp. Paratype, Univ. Calif. Mus. Paleo. no. 12602. The apparent extension of mouthparts is actually debris in the amber matrix. ×57.4. Photograph by Hal Roth.



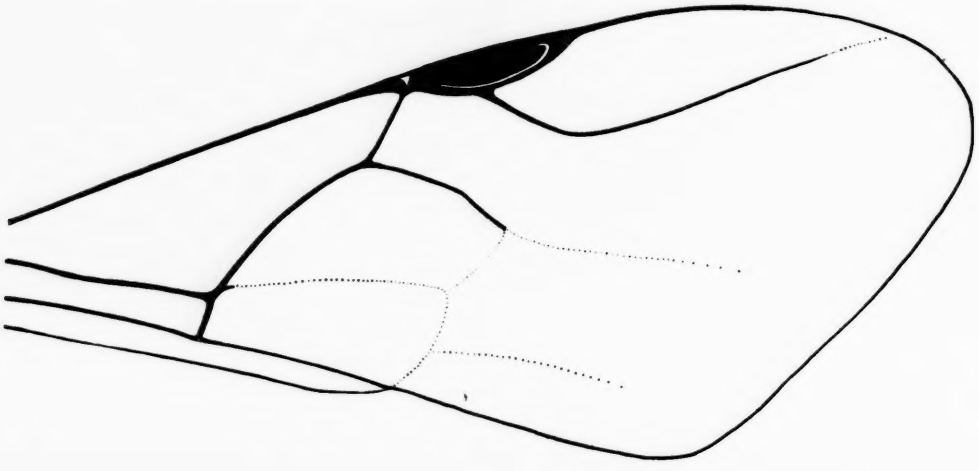
1



2



3



4

1 MM

inal tergum; inner and outer sides of posterior and distal borders of hind tibia; hind basitarsus. Dark areas appear either brown or black according to the direction of light. Surface polished with evenly distributed sparse punctation.

Head.—Width 1.2 times length; length of eye 3.2 times breadth; scape not reaching anterior ocellus; third antennal segment as long as fourth; antennal sockets well below middle of face and immediately above epistomal suture (text-fig. 1); subantennal sutures absent; interantennal space twice width of flagellum (width of flagellum 0.0750 mm.); width of clypeus 2.2 times its length; lateral portions of epistomal suture almost straight and diverging anteriorly; malar space equal to or slightly less than width of flagellum; preoccipital ridge absent; labrum slightly emarginated; inner third of apex of mandible bidentate; length of glossa apparently equal to or less than length of prementum.

Thorax.—Pronotum as long as flagellar width; anterior border of pronotum slightly concave; width of mesoscutum 1.1 times its length; scutellum short but extending backwards slightly, not as far as end of propodeum, covering mesal portion of metanotum as seen from above, and with apex rounded; width of scutellum 1.9 times its length; distance between lower metapleural suture and second coxa less than half width of flagellum; basal area of propodeum glabrous; length of propodeal spiracle 3.3 times its width.

Legs.—Hind femur with anterior surface broadly concave, 1.4 times as wide as flagellum. Inner surface of hind basitarsus without sericeous area; length of basitarsus twice its width; distal angles of basitarsus at about same level. Shape of hind tibia triangular, with posterior distal angle rounded; length of hind tibia 2.8 times its width; corbicula occupying distal two thirds of tibia; marginal hairs of hind tibia simple; hind tibia with an apparently median and sparsely hairy elevation that extends through whole length of inner surface, leaving flat anterior and posterior rims that widen at apex, anterior rim well differentiated and from median elevation by a relatively high wall (0.0450 mm.), distal half of posterior rim about same level as median elevation, but differentiated from it by dark coloration and lack of hairs; relative width of anterior rim, median elevation, and posterior rim where tibia is widest: 5:11:5; comb well developed (text-fig. 3); rostellum composed of about 14 long hairs, slightly longer than width of flagellum, and restricted to distal width of median elevation.

Wings.—Length 2.7 mm.; the following veins weakly indicated: Cu, Cu_1, Cu_2, 1st m-cu, 2nd m-cu, and following abscissae of M; submarginal cells virtually absent; length of pterostigma 4 times its width; length of cu-v same as width of pterostigma; length of marginal cell 4 times its width; submarginal angle (basal angle of cell of 1st R_1) about 75°; base of 1st medial cell petiolate (text-fig. 4); 5 hamuli. The wing terminology follows that of Michener (1944).

Abdomen.—Relatively short and wide, subtriangular, with dorsal surface slightly convex; sting undeveloped; gonostylus slightly longer than width of flagellum.

Type material.—Holotype worker (Univ. Calif. Mus. Paleo. no. 12601) from Rio San Pedro, opposite town of San Pedro, Simojovel area, Chiapas, Mexico, and ten worker paratypes (Univ. Calif. Mus. Paleo. nos. 12602–12611) from the Simojovel landslide, Simojovel, Chiapas, Mexico. According to J. Wyatt Durham the beds at the Simojovel landslide are about middle Miocene in age and the Rio San Pedro locality might be of the same age. The amber pieces were collected over the past several years by Frans Blom and Gertrude Duby.

ACKNOWLEDGMENTS

Acknowledgment is made to the Associates in Tropical Biogeography of the University of California who have supported the field explorations and acquisition of the

TEXT-FIGS. *1–4*—*Trigona* (*Nogueirapis*) *silacea*, n. sp. *1*, anterior view of head. *2*, lateral view of head, pedicel and flagellum omitted. *3*, inner view of left hind tibia and basitarsus. *4*, right fore wing, hairs omitted. Figures based primarily on the holotype, Univ. Calif. Mus. Paleo. no. 12601.

Chiapas amber, and to J. Wyatt Durham of the Museum of Paleontology, and P. D. Hurd, Jr. and Ray F. Smith of the Department of Entomology and Parasitology, University of California, who have made this fossil material available for study.

LITERATURE CITED

HURD, P. D., JR., & SMITH, R. F., 1957, The meaning of Mexico's amber: Pacific Discovery, Calif. Acad. Sci., v. 10, no. 2, p. 6–7.

MICHENER, C. D., 1944, Comparative external morphology, phylogeny, and a classification of the bees (Hymenoptera): Bull. Am. Mus. Nat. History, v. 82, p. 153–326.

MOURE, PE. J. S., 1953, *Nogueirapis*, no grupo de Trigonini de região neotropical. (Hymenoptera-Apoidea): Ciencia e Cultura, v. 5, no. 4, p. 247–249.

ROTH, HAL, 1958, New fossil find: Nat. History, Mag. Am. Mus. Nat. History, v. 67, no. 4, p. 223–225.

SCHWARZ, H. F., 1948, Stingless bees (Meliponidae) of the Western Hemisphere: Bull. Am. Mus. Nat. History, v. 90, p. 1–546 (section on fossil records, p. 8–9).

TOSI, ALESSANDRO, 1896, Di un nuovo genere di Apiaria fossile nell'ambra di Sicili (*Meliponorytessuccini—M. sicula*): Riv. Italiana Paleontologia, v. 2, p. 352–356.

MANUSCRIPT RECEIVED OCTOBER 16, 1958

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, PP. 853–854, 6 TEXT-FIGS., SEPTEMBER, 1959

A NEW HEMIPTERAN (DIPSOCORIDAE) FROM THE MIOCENE AMBER OF CHIAPAS, MEXICO

PEDRO WYGODZINSKY
Instituto Miguel Lillo, Tucumán, Argentina

ABSTRACT—The first recorded fossil dipsocorid hemipteran insect, *Ceratocombus* (*Ceratocombus*) *hurdi*, n. sp., is described from the middle Miocene of the Simojovel area, Chiapas, Mexico

THIS specimen, which is the first fossil dipsocorid known, seems to agree perfectly with recent species of *Ceratocombus* (*Ceratocombus*) as to its generic characters, as well as can be judged from a female.

Ceratocombus (*Ceratocombus*) *hurdi* n. sp.

Macropterous female.—Length to apex of fore wings, 1.3 mm. Body shape elongate oval.

Color (as apparent in the yellowish amber) brown, fore wings somewhat darker, antennae, rostrum and legs yellowish. Corium and apex of membrane of fore wings somewhat hyaline.

Shape of head dorsally as in text-fig. 1. 1+1 macrochaetae dorsally near border of eyes, 2+2 on eyes; some of the other macrochaetae of head as in text-fig. 1. Ocelli? First segment of antennae short, shape and chaetotaxy of segments II–IV as in text-fig. 2; IV distinctly longer than III. Rostrum slender, reaching to midcoxae; first segment the shortest, second distinctly longer than third.

Pronotum as in text-fig. 1, width across humeri equal to twice its length along midline. Lateral borders not emarginate; sculpture of dorsal surface not observable. 1+1 macrochaetae each near anterior and posterior angles; surface with very numerous rather uniformly distributed microchaetae. Scutellum as usual, somewhat depressed on disc.

Legs as usual for the genus, rather short; tarsal formula, 3, 3, 3; all tarsi long and slender (text-figs. 3, 4).

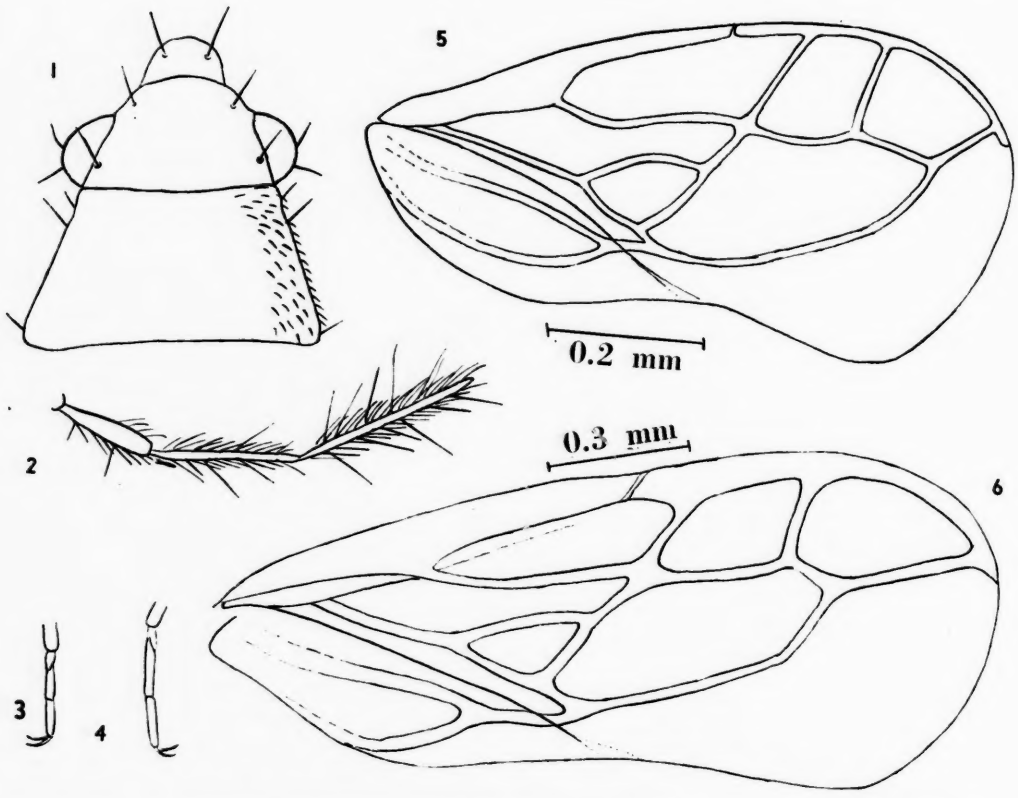
Fore wings as in text-fig. 5, rather short, surpassing apex of abdomen by 0.2 mm.; membrane somewhat truncate apically. Costal margin wide at base, abruptly narrowed at origin of R+M, continuing narrow to slightly beyond last marginal cell, not widened at or beyond fracture. R+M distinctly curved. Portions of vein separating discal and marginal cells of membrane of approximately equal length. Veins of clavus, corium and membrane with one somewhat irregular row of bristles; cells and apex of membrane with irregularly distributed microtrichia. Hing wing complete, as long as fore wing, with at least one incision.

Some of the characters of this insect (presence or absence of ocelli, details of structure of abdomen) could not be examined owing to the state of preservation of the specimen.

Material examined: holotype female (Univ. Calif. Mus. Paleo. no. 12612) from Simojovel landslide, Simojovel, Chiapas, Mexico. This specimen was collected by Gertrude Duby. According to J. W. Durham the beds at the Simojovel landslide are about Middle Miocene in age.

Only very few of the extant species of *Ceratocombus* (*Ceratocombus*) have been named, and most of these have been described superficially only. Though it is fairly safe to say that *C. hurdi* is different from any named species, there are no data available for excluding the possibility that it might have survived to the present day. Stebbins (Variation and evolution in plants. Ed. 2. XX+643 pgs. 1951. Columbia University Press) gives a list of numerous woody plants which have continued "practically unchanged" for 20 to 30 million years, though of course the evolutionary history and possibilities of woody plants and dipsocorids might not be directly comparable.

For comparative purposes, the forewing of a macropterous female of *Ceratocombus coleoptratus* (Zetterstedt, 1819), the type of the genus, is figured here (text-fig. 6); this species differs from *C. hurdi* by the much larger size (about 2 mm. in the macropterous form), the different shape of the fore



TEXT-FIGS. *1–5—Ceratocombus* (*Ceratocombus*) *hurdi* Wygodzinsky, n. sp. *1*, head and pronotum, dorsal view; *2*, antenna, three distal segments; *3*, anterior tarsus; *4*, posterior tarsus; *5*, forewing. *6*, forewing of *Ceratocombus coleoptratus* (Zetterstedt).

wing and its cells, and the costal margin which is only gradually narrowed beyond the origin of R+M and much wider apically than in *C. hurdi*. The costal margin of the fore wing of *C. hurdi*, abruptly narrowed at the origin of R+M and not widened at or beyond fracture, serves to distinguish the the new species from *C. areolatus* McAtee & Malloch, 1925, *C. brasiliensis* Reuter, 1891, *C. bifenestratus* Poppius, 1910, *C. hesperus* McAtee & Malloch, 1925, *C. japonicus* Poppius, 1910, *C. plebejus* Poppius, 1910, *C. sumatranus* Poppius, 1910 and *C. yunquensis* Usinger, 1946 though probably many additional characters could be found upon careful comparison. The following species are known from brachypterous forms only and cannot be compared directly to the species under discussion: *C. brevipennis* Poppius, 1910, *C. fasciatus* (Uhler, 1894), *C. lusaticus* Jordan, 1943, and probably also *C. insularis* Reuter 1893. *D. niger* Uhler, 1904 is not identifiable, and the data for *C. panamensis* Champion, 1900, are not sufficient for comparison.

Acknowledgment is made to the Associates of Tropical Biogeography of the University of California who have supported the field explorations and acquisition of the Chiapas amber, and to J. Wyatt Durham of the Museum of Paleontology, and P. D. Hurd, Jr. and Ray F. Smith of the Department of Entomology and Parasitology, University of California, who have made this fossil material available for study.

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 855–871, 1 TEXT-FIG., SEPTEMBER, 1959

PALEOECOLOGY OF A MOLLUSCAN FAUNA FROM THE TRENT FORMATION

A. BARRETT SMITH
University of Washington, Seattle

ABSTRACT—A new locality of the Miocene Trent formation was discovered at Silverdale, Onslow County, North Carolina. Here the formation is an unconsolidated shell marl. The fauna is entirely molluscan.

A complete faunal list for the Trent is given showing the species collected by earlier investigators and the number of specimens of each species collected at the new site. The ecology of Recent species of the genera collected from Silverdale was studied from the literature. From this data, the paleoecology of the community was interpreted.

The Silverdale community lived in marine waters at depths of about 3 to 22 fathoms. The temperature of the water was from 7 to 40°C. with the average high near 28 to 30°C. The mollusks lived on a sandy to muddy sand substrate in moderately swift currents.

INTRODUCTION

THE aim of this paper is to interpret the paleoecology of a faunal assemblage from the Trent formation. A faunal list was compiled from the literature including all the fossils reported from the formation and the localities from which they were collected.

During the summer of 1957, several Trent localities near Silverdale and Belgrade, Onslow County, North Carolina, were visited. An extensive collection was made from a previously undescribed locality on the farm of John M. Gillette. The specimens obtained were identified and are listed in the text. A few fossils were collected at the site of the Superior Stone Company in Belgrade but these were poorly preserved impressions. They are listed in the text but are not considered in the ecology section.

All of the genera collected from the John M. Gillette site have species living today. Mollusks belonging to these genera found along the North American coasts today were studied from the literature in regard to their geographical distribution, depth, substrate on which they occur, temperature range, salinity tolerance, current requirement, food and predators. This data was summarized for each genus. In cases where depth ranges were originally in feet, they have been converted to fathoms; fractional numbers were rounded off to the nearest fathom. From this information the ecology of the Trent formation was interpreted.

It should be pointed out that, in general, the ecology of living groups of marine mollusks is poorly understood. The most extensive work has been done on species with commercial value such as *Ostrea*, *Mercenaria mercenaria* and *Mytilus edulis*. In many cases, the only information concerning the habitat of a species is a poorly documented vertical range. Because of such a lack of vital information concerning modern ecology, the interpretation presented here is generalized and incomplete.

PREVIOUS WORK

The Trent formation was named by Miller (1912, p. 175) for the Trent River, along which it is exposed. Miller stated that it outcropped from the vicinity of Trenton, Jones County, North Carolina to near the junction of the Trent and Neuse Rivers. He described it as "composed of calcareous marls, fossiliferous limestone, and fine-grained, siliceous sandstones deposited under marine conditions and extending inland from the coast south of the Neuse River to Wake, Moore and Harnett Counties." Although the two formations have never been seen in contact, the Trent was believed to underlie the Castle Hayne formation. From the identification of four echinoids, *Scutella alta* Conrad, *Echinocyamus parvus* Emmons, *Cidaris carolinensis* Emmons and *C. mitchelli* Emmons, M. W. Twitchell concluded that the Trent formation is upper Claibornian. He gave no locality for his fos-

sils. Only *Echinocyamus parvus* has been recognized elsewhere; it occurs in typical deposits of the Castle Hayne formation, in Onslow County.

Harris (1919, p. 15) described two new species of *Pecten* from the Trent at a site about six miles below Pollocksville, North Carolina. They are *Pecten trentensis* and *P. elixatus*. Of the former he states: "the general appearance of this shell is so different from anything we have heretofore found in the Eocene of this part of the United States that, owing to a lack of well-known species from the same locality, its horizon must be considered as doubtful."

Kellum (1926) extensively studied the area. Of the twenty-three stations listed by Miller as being Trent, he found that seven failed to yield fossils and seven proved to be Castle Hayne. A bed of well preserved molluscan fossils was discovered on the farm of John H. Gillette, along the left bank of Webbs Creek, one-half mile southeast of Silverdale, Onslow County, North Carolina. On the basis of this fauna, he determined that the Trent formation was of Lower Miocene age. In the same paper Kellum confirmed the age of the Castle Hayne as being Upper Eocene. Consequently, he showed that the Trent lies above the Castle Hayne and not below it as previously believed. He redefined the boundaries of the formation, stating that the Trent is exposed in a north-south belt between the New and Neuse Rivers and is found in Onslow, Jones, and Craven Counties.

Richards (1943) reported additions to the Trent formation. He visited the site on the Gillette farm and located a new locality at the Askew Marl Pit, two miles northwest of Silverdale. At the latter site, the formation is an unconsolidated marl consisting mostly of shells. The matrix is a weathered yellow sand. Here the Trent is overlain by the Croatan sand (Pliocene). Richards (1950, p. 19) gave a description of the Trent as it is now understood. He said that north of New Bern, it is overlain by the Yorktown formation. In this area it is a consolidated shell rock and is used extensively for road fill. The formation is less than 200 feet thick and dips gently seaward. Richards stated that the fossils discovered by him confirm the lower Miocene age of the formation and he agrees with Kellum as to the stratigraphic position and extent of the Trent.

A NEW LOCALITY

The marl pits on the farm of John H. Gillette, first discovered by Kellum and studied later by Richards, are no longer in use. The site has been covered with fill and is overgrown with brush. A few broken shell fragments can be found scattered about in the yellow clayey soil. This defunct pit is on the east side of Webbs Creek and on the east side of the road leading from North Carolina State Highway route 24 to Silverdale. The pit is one-half mile south of Silverdale and is about one-quarter mile east of the road.

A new marl pit has been dug about three-quarters of a mile south of Silverdale on the farm of John M. Gillette, the son of John H. Gillette. It is on the west side of the road leading from North Carolina State Highway route 24 to Silverdale. The pit is about 300 yards from the road, not far from the bank of Webbs Creek. It has been excavated by power shovel and bulldozer. The pit, approximately ten feet deep, perpetually fills with water and must be pumped constantly. At each of five visits made to this area over a six week period, the pit was filled with water. Consequently, it was impossible to collect from the outcrop. According to Mr. Gillette, the shell bed, which is about four feet thick, occurs just below the soil layer and about three feet below the surface. It is underlain by a sandy bed.

A comparison of the list of those mollusks collected at this site with the faunal list of the Trent formation leaves little doubt that this is another exposure of the Trent formation.

The material collected was from large mounds formed by the bulldozer. The shells make up nearly fifty percent of the rock. An unconsolidated clayey sand constitutes the remainder. A few pelecypods with both valves intact were found. Most of the fossils were in excellent condition, showing clearly all morphological features. For this reason, it is believed that the mollusks were preserved where they lived and were not transported after death. If this is true, the fossil assemblage represents an ancient community and is not composed of several communities brought together after they died. It is

possible, of course, that a few shells were carried by currents into the area after death.

NOTES ON FOSSILS COLLECTED

A complete faunal list for the Trent formation is given later in the text. This includes the fossils collected during the current investigation (see text-fig. 1 for locations of all three collecting localities). Some of these deserve further mention and will be discussed briefly below. A few specimens were collected from the pits of the Superior Stone Company and are also mentioned.

Cardita arata Conrad

This species has not been previously reported from the Trent formation. As it was impossible to collect from the outcrop at the new site, it can not be definitely shown that the three left valves collected are from the Trent. However, since the majority of the species collected during the study closely agree with Trent fauna, it seems more than likely that *C. arata* from the same locality is also from the Trent.

Cardium belgradensis Richards

Three impressions of this species were collected at the pits of the Superior Stone Company, Belgrade. These are in the collection of the Museum of Paleontology at the University of Michigan, catalog number 35134.

Chione latilirata Gould

A single right valve of this species was collected at the new site. It is not included in the ecological study. It bears catalog number 35111.

Mytilus sp.

A single specimen belonging to this genus was collected during the current investigation, from the new site. It was poorly preserved and has not been specifically identified.

Ostrea georgiana Conrad

One large specimen was collected at the new site. It is in the collection of the Institute of Fisheries Research, University of North Carolina, Morehead City, N. C. Fragments of oyster shells are common in this area but complete valves are rare.

Panope intermedia Richards

Impressions of this species are common at the pits of the Superior Stone Company. Several were collected and are cataloged under number 35119.

Phacoides wacissanus Dall

Two complete specimens were collected at the new site. The smaller of the two was attached to the left valve of a young *Venericardia* and was in perfect condition. This is evidence in favor of the idea that the animals were preserved in their natural habitat. This attachment is so fragile that it seems likely that any transportation after death would separate the two animals.

An impression of the upper valve of this species was collected from the pits of the Superior Stone Co. It bears catalog number 35113.

Venus gardnerae Kellum

Impressions of this species were collected at the Superior Stone Company site and are cataloged under number 35115. Well preserved shells were collected at the new Gillette site.

Calyptraea aperta Solander

Two specimens were collected at the new Gillette site and a single impression was taken from the pits of the Superior Stone Co. The latter is cataloged 35140.

Busycon sp.

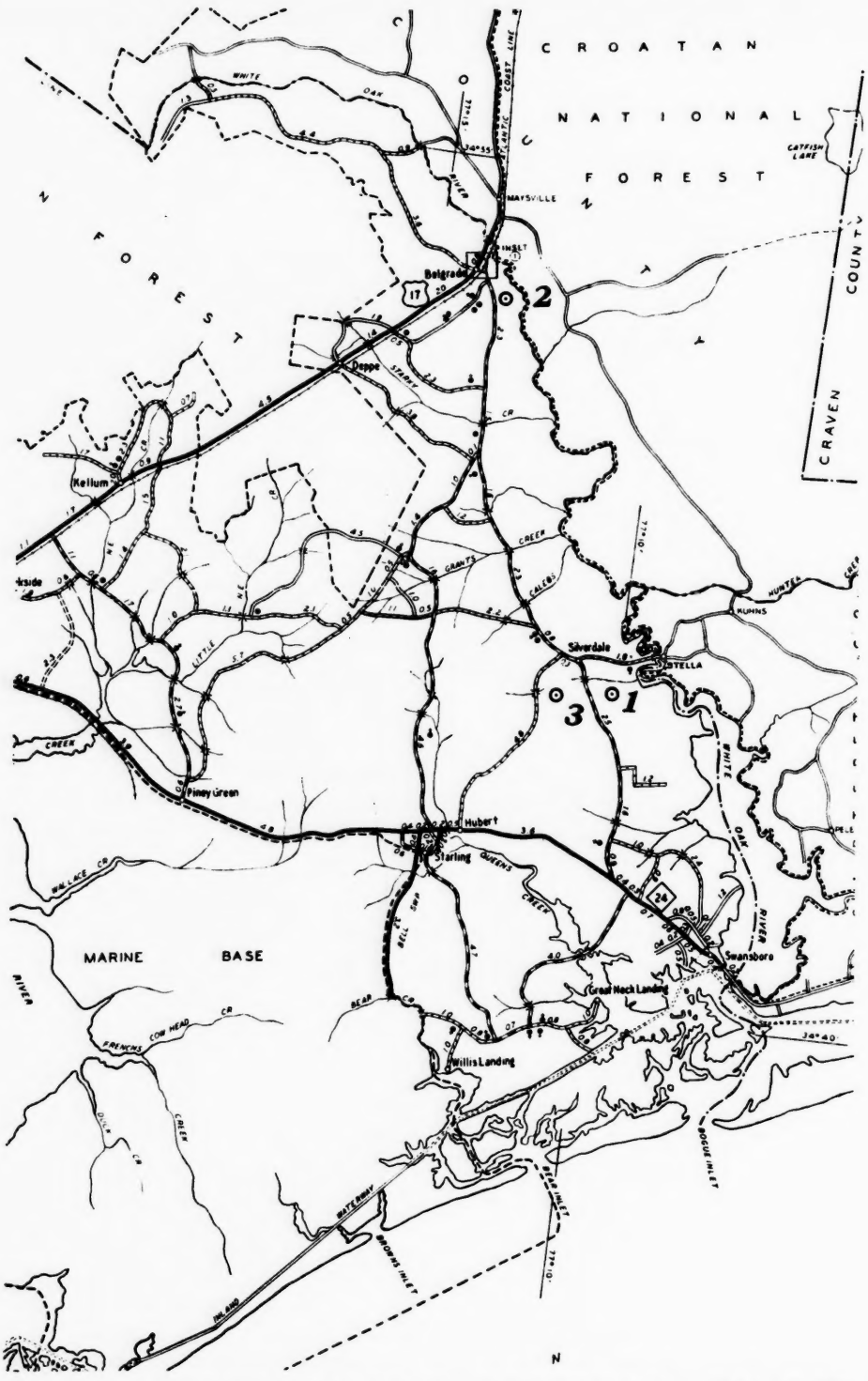
Along with 12 specimens of *B. spiniger onslowensis* Kellum, a fragmentary specimen of another species was collected from the new Gillette site. It is in the University of Michigan, Museum of Paleontology collection, no. 35144.

ECOLOGY OF LIVING SPECIES

Family Arcidae

Arca

The genus *Arca* is distributed throughout the world in modern seas. It has a vertical range of 1 to 600 fathoms. Many species attach by a byssus to rocks or shell fragments. Others crawl about in mud and sand on the bottom. Though no data concerning the sa-



TEXT-FIG. *1*—Index map of fossil localities. *1*, the original marl pits on the farm of John H. Gillette; *2*, the marl pits of the Superior Stone Company at Belgrade; and *3*, the new collecting site on the farm of John M. Gillette.

linity tolerance of this genus have been uncovered, it is assumed that the optimum salinity is near that of normal sea water in the open sea. According to Sverdrup (1942, p. 55) this is 34.324 parts per thousand.

A. zebra Swainson is known from Cape Hatteras, North Carolina to Cuba and is most common in water 1 to 2 fathoms deep. According to Abbott (1954, p. 342), the synonym *A. occidentalis* Philippi is more common in the literature than the valid name. *A. umbonata* Lamarck is known from Cape Hatteras to Brazil. Abbott (1954, p. 342) states that it is found along the underside of rocks in shallow water.

Family Carditidae

Cardita

Cardita floridana Conrad is known along the Atlantic coast from Florida to Mexico. It is abundant in bays and coves and similarly protected bodies of water. It is commonly found in mud, ranging from a few feet below the water line down to considerable depth. *C. dominquensis* d'Orbigny occurs along the Atlantic from Hatteras to Florida. It has, according to Abbott (1954, p. 378), a vertical range of 1 to 70 fathoms and is said to prefer sandy bottoms.

Venericardia

V. tridentata Say is known from Cape Hatteras to Florida in water 32 to 124 fathoms deep. *V. perplana* Conrad has a similar geographical distribution but Maury (1920) says it is limited to 15 to 52 fathoms.

Family Crassatellidae

Crassatellites

According to Abbott (1954, p. 377), *Crassatellites* Krueger is invalid and the genus is now referred to as *Eucrassatella* Iredale under the family Crassatellides. *Crassatella* Lamarck is fossil and not Iredale's genus.

Crassatellites gibbesi Tuomey & Holmes and *C. floridana* Dall are, according to Abbott (1954), synonyms for *Eucrassatella speciosa* A. Adams. This species is known along the Atlantic coast from Cape Hatteras to Barbados. Maury (1920) states that it occurs between 3 and 100 fathoms. It is most common on sandy bottoms.

Family Diplodontidae

Diplodonta

The ecology of this genus is not well understood. *D. punctata* Say is known from North Carolina to Florida and the West Indies. It is said to be common in shallow to deep water (Abbott, 1954, p. 383). *D. semiaspera* Phillippi is known from North Carolina to Texas and the West Indies. It is found on sandy bottoms between 1 and 40 fathoms.

Family Donacidae

Donax

This genus has been reported as worldwide in warm seas. Most contemporary members are found on sandy beaches in the surf washed zone facing the open sea. They burrow just beneath the surface of the moist sand near the upper edge of the littoral zone to a depth of about 2 fathoms. The salinity in this area is usually near 34.325 parts per thousand. Among those species with this habitat are: *D. semigranosis* of Japan, *D. variabilis* Say from along the Atlantic coast from Virginia to Texas, *D. tumida* Phillippi which ranges from St. Augustine, Florida, to Texas, *D. fossor* Say from Long Island, New York, to Cape May, New Jersey, and *D. laevigata* Deshays of the Californian coast. Of the latter species Weymouth (1920) states, "It is found on exposed sandy beaches though it appears at times to prefer some slight degree of protection such as that offered by a position near the entrance to a bay or behind a sand bar."

D. californicus Conrad, according to Weymouth (1920), occurs on the Pacific coast from Santa Barbara, California to Panama. It has been found to frequent sheltered areas near the mouths of bays. It occurs between tide levels on sandy beaches not exposed to surf action.

Parker (1956) states that concentrations of *Donax* and *Olivella* shells may be used to indicate the gulf side of barrier islands. Though *Olivella* was not collected during the current investigation it has been reported by Richards (1943, p. 525). Because it is relatively small, careful washing of the matrix might reveal more specimens. Until then, it will not be possible to consider either genus

TABLE 1.—FAUNAL LIST OF THE TRENT FORMATION*

Species	Collector			John M. Gillette Farm	
	Harris	Kellum	Richards	No. Specimens	Catalog No.
Anomia onslowensis Richards	—	—	1, 3	—	—
Antigona lamellacea Kellum	—	1	1, 4	—	—
Arca silverdalensis Kellum	—	1	1, 4	5L 1R	35124
Astarte onslowensis Kellum	—	1	1, 4	—	—
Callista neusensis (Harris)	10	1, 5, 6, 7, 8, 9	1, 4	17L 22R	35132
Cardita arata Conrad	—	—	—	3L	35127
Cardium belgradensis Richards	—	—	3	—	—
C. midyetti Richards	—	—	1	—	—
Chione latilirata Conrad	—	—	—	1R	35111
Corbula burnsi Dall	—	—	1	—	—
C. idonea Conrad	—	—	1	—	—
Crassatellites mississippensis var. *silverdalensis* Kellum	—	1	1, 4	4L 1R 1C	35118
Diplodonta alta Dall	—	—	1	1L 1R	35137
Donax idoneus Conrad	—	—	1	1R	35131
Gemma magna Dall	—	—	1	—	—
G. magna striata Richards	—	—	1	—	—
Glycymeris anteparilis Kellum	—	1	1	12L 19R	35139
Macrocallista tia Kellum	—	1	1, 4	11L 11R	35130
Modiolus stuckeyi Richards	—	—	3	—	—
Mytilus conradinus d'Orbigny	—	—	1	—	—
Ostrea georgiana Conrad	—	—	1, 3	1F	—
Panope intermedia Richards	—	—	3	—	—
Pecten elixatus Conrad	12	—	—	—	—
P. trentensis Harris	12	—	—	—	—
Phacoides nocariensis Kellum	—	1	—	1R	35121
P. silicatus Mansfield	—	—	1	—	—
P. wacissanus Dall	—	—	—	1R	35138
Plicatula densata Conrad	—	1	1, 4	2C	35112
Venericardia granulata Say	—	1	1, 4	2L 2R	35125
V. nodifera Kellum	—	1	1	4L 9R 1C	35136
Venus erecta Kellum	—	1, 5, 6, 12	1, 4	2R	35347
V. gardnerae Kellum	—	1, 6	1, 3	9L 4R	35346
Busycon filosum Conrad	—	—	1	—	—
B. spriniger onslowensis Kellum	—	1	1, 4	12	35129
Calyptraea aperta Solander	—	—	1, 4	2	35140
C. trochiformis Lamarck	—	1	1, 4	—	—
Conus postalveatus Kellum	—	1	1, 4	25	35143
Coralliophila cumberlandia (Gabb)	—	—	1	—	—
Crepidula fornicata (Linne)	—	—	1, 4	—	—
C. plana Say	—	—	1	—	—
Crucibulum constrictum (Conrad)	—	—	1	1	35123
Diadora chipolana caroliniana Richards	—	—	1	—	—
Ecphora quadricostata (Say)	—	—	1	—	—
Eupleura harbisonia Richards	—	—	1	—	—
Fusinus trentensis Richards	—	—	1	—	—
Leiostrichus sp.	—	—	1	—	—
Lyria carolinensis Kellum	—	1	—	3	35120
Murex davisi Richards	—	—	1	9	35116
M. kellumi Richards	—	—	1	—	—
Oliva posti Dall	—	1	1	—	—
Olivella gardnerae Richards	—	—	1	—	—
Polinices duplicata Say	—	—	1, 4	9	35126
P. hemicrypta (Gabb)	—	—	1	—	—

* The numbers below the names of the three collectors correspond to the numbers preceding the collecting localities in the key to collecting localities. Under number of specimens L refers to left valve, R to right valve, C to complete specimen, and F to fragment. The catalog numbers refer to the specimens collected during this investigation from the John M. Gillette farm. All of these specimens are in the collections of the Museum of Paleontology, University of Michigan.

TABLE 1—*Continued*

Species	Collector			John M. Gillette Farm	
	Harris	Kellum	Richards	No. Specimens	Catalog No.
P judsoni (Maury)	—	—	1	—	—
Potamides silverdalensis Richards	—	—	1	—	—
Rapana biconica Dall	—	—	—	1	35138
R. gilletti Richards	—	—	1	1	35122
R. vaughana Mansfield	—	—	1, 4	—	—
Scaphella stromboidella Kellum	—	1	1, 4	5	35142
Sinum imperforatum Dall	—	1	1, 4	1	35114
Siphonalia migrans (Conrad)	—	—	1	—	—
Terebra whitfieldi Martin	—	—	1	—	—
Turritella fuerta Kellum	—	1	1, 4	25	35133

KEY TO COLLECTING LOCALITIES

1. Farm of John H. Gillette, Silverdale.
2. Farm of John M. Gillette, Silverdale.
3. Superior Stone Company, Belgrade.
4. Farm of A. W. Askew, two miles northwest of Silverdale and one-half mile east of the highway.
5. Jacksonville, at the east end of the wagon bridge over the New River.
6. White Rock Landing, on the left bank of the Trent River about twelve miles above New Bern.
7. Rock Springs, on the right bank of the Trent River three and one-half miles upstream from New Bern, on the farm of James N. Smith.
8. Along the Neuse River nine miles northwest of New Bern.
9. Along the Neuse River twelve miles northwest of New Bern.
10. Rock Landing, on the Neuse River about sixteen miles above New Bern and three miles east of Jasper.
11. Along the right bank of the Trent River about six miles below Pollocksville.
12. Nine miles northeast of Jacksonville.

as occurring in concentration. However, because they are present one must consider this environment as possible.

Family Glycymeridae

Glycymeris

Of the fossil species of *Glycymeris*, *G. anteparilis* Kellum is most closely related to *G. parilis* (Conrad). According to Nicol (1953, p. 451) the species most nearly related to *G. parilis* on the basis of shell morphology is *G. americana* (Defrance). Accordingly, *G. anteparilis* is also closely related to *G. americana*, which is found along the Atlantic coast from Cape Hatteras to Florida. The majority of the specimens at the National Museum are recorded as having been dredged from a sand bottom at depths ranging from 7 to 33 fathoms (Nicol, 1953). However, a few were collected in waters as deep as 80 fathoms.

Species of *Glycymeris* are known in tropical and temperate waters around the world. A few more North American examples follow. *G. pectinata* Gmelin, with a vertical range of 6 to 525 fathoms, is known from Cape Hatteras, North Carolina to Nicaragua. *G. subobsoleta* Carpenter lives in shallow to deep water along the Pacific coast from the Aleutian Islands to lower California. *G. spectralis* Nicol (1952, p. 266) is found from Shackleford Island, North Carolina, to Florida and from Tampico, New Mexico, to Costs Rica. It inhabits sandy bottoms at depths between 8 and 9 fathoms.

Members of this genus probably live within a range of 3 to 568 fathoms. If *G. anteparilis* has a vertical range similar to that of the closely related species *G. americana*, the shells found in the Trent formation, lived at depths of 8 to 35 fathoms. This possibility is compared with other evidence later. The genus is a sandy bottom and open ocean group.

Family Lucinidae

Phacoides

Among the species of *Phacoides* living in North America are *R. pectinatus*, *P. nassula*, *P. nuttali*, *P. filosus*, and *P. annulatus*. *P.*

pectinatus Gmelin is known from North Carolina to Texas and the West Indies. It is common in shallow water. *P. nassula* Conrad is found along the Atlantic coast from North Carolina to Florida, Texas, and the Bahamas. Parker (1956) gives the range of 30 to 35 fathoms for the species off the Mississippi Delta. According to Abbott (1954), in some parts of its geographical range the species lives at a depth of 100 fathoms. *P. nuttalli* Conrad is known from Santa Barbara, California, to Manzanillo, Mexico. It is common just off shore on a sandy bottom. *P. filosus* Stimpson is found along the Atlantic coast between Newfoundland and the Gulf of Mexico. *P. annulatus* Reeve, known from Alaska to Southern California, ranges from 8 to 75 fathoms.

The range of the genus is therefore between 1 and 100 fathoms. It is an open ocean group.

Family Mytilidae

Mytilus

The two most common Recent North American species are *Mytilus edulis* Linné and *M. californianus* Conrad. *M. edulis* is circumpolar, extending down the eastern coast of North America to North Carolina and down the western coast to San Francisco, California, down the Asiatic coast to Japan, and down the European to the Mediterranean. Although it thrives in slightly brackish water, it is also abundant in normal sea water. This species is found on sandy bottoms, but it is much more common on a rocky substrate in shallow sheltered bays and coves. These clams are found on muddy bottoms only where there are rocks, shell beds, or pilings upon which they may attach. The bathymetrical range for the species is from sea level to about 100 fathoms. Channels of swift currents in shallow inlets are good locations for these mussels, inasmuch as they procure their food from suspended matter in sea water. Strong currents are most likely to provide a continuing supply of food. The upper temperature limit to survival is 40.8°C. (Gunter 1957, p. 163). No figure can be found for the lower limit. It is assumed to be relatively low, since *M. edulis* is common in the Arctic Ocean.

Mytilus californianus Conrad is found along the Pacific coast from the Aleutian Islands to as far south as Socorro Island, Mexico. Under normal conditions, this species will secrete a byssus, ingest food, and discharge feces at temperatures as high as 24 to 26°C. and as low as 7 to 8°C. (Coe & Fox, 1944). Those specimens subjected to temperatures as high as 27 to 28°C. died within 5 to 7 days. It should be pointed out that this is considerably lower than the upper limit given by Gunter (1957) for *M. edulis*. *M. californianus* is a scavenger, feeding on unicellular organisms and particulate disintegration products of any of the animals which are brought to it by currents. It is found above rocky and sandy bottoms bordering the open sea. It attaches to rocks, shell bars, and pilings from high tide level to the level of the lowest ebb. These animals do not flourish in quiet waters.

For the genus *Mytilus* we can make the following generalizations. It has an attached habit and may be found in either open seas or quiet bays. Slightly brackish to normal sea water is preferred. The temperature limits are 7 to 40.8°C. This upper limit must be considered questionable until more work is done concerning the limits of *M. edulis*. The most favorable substrate is sand, although rocky and muddy bottoms can be tolerated.

Family Ostreidae

Ostrea and *Crassostrea*

The oysters are, perhaps, the most thoroughly studied pelecypod group. This is due, chiefly, to their commercial value. The most famous species in this country is *Crassostrea virginica* Gmelin, which is served in restaurants throughout the continent. Its geographical range extends from the Gulf of St. Lawrence to the Gulf of Mexico. *C. gigas* Thunberg ranges from the coast of British Columbia to California. It is not, however, a native of these waters, having been introduced from Japan. *O. equestris* Say is known from North Carolina to the West Indies in the Gulf of Mexico. *O. frons* Linné is found along the Atlantic coast from Florida and Louisiana to the West Indies. *O. permollis* Sowerby ranges between North Carolina and Florida. *O. lurida* Carpenter, native of the Pacific, is known from Alaska to lower

California. *O. cucullata* Awati, the "Bombay Oyster," is common in India. *O. chiloensis* (Sowerby) is known off the Chilean coast. *O. taurica* is found in the Black Sea off the coast of Georgia according to Nikitin (1934).

The optimum depth for *C. virginica* ranges from the shore line to about 15 fathoms. The maximum range is from 0 to 22 fathoms. *O. lurida* is most common along the intertidal zone, as is *O. cucullata*. *O. chiloensis* grows at depths of about 2 or 3 fathoms, according to Castillo (1907). *O. taurica* has a range of 0 to 20 fathoms.

A bottom of soft mud into which the young oysters would sink is unfavorable to the natural development of oyster beds. If, however, hard objects are distributed over the substrate, they will collect the spat as long as their surface remains free of slime and sediment. The ideal substrate for oysters is firm sand or shell bars. However, *O. lurida* is able to live on mud flats near the mouths of rivers and *O. cucullata* is found attached to rocks.

C. virginica lives in water of widely varying temperatures. In Chesapeake Bay, for example, the range in temperature of the water over the oyster beds is from 0 to 32°C. In many areas oysters exposed at low tides are frozen. If thawing is slow, most will survive. In deeper waters such as those over the beds along Long Island Sound, oysters are not subjected to such extreme temperature fluctuations. Even here, they may be subjected to such extremes as 1.5°C. in the winter and 24°C. in the summer. In contrast, water over commercial beds in South Carolina seldom falls below 13°C. In the Gulf of Mexico the water is usually between 13 and 32°C.

Churchill (1919) states that the American oyster (*C. virginica*) will spawn when the water reaches a temperature of 20°C. but normal spawning speed is reached only when the water has reached a temperature above 21°C. Nelson (1928) states that the European oyster, *O. edulis*, spawns when the temperature reaches 15°C. *O. cucullata* has been shown to have an optimum temperature for reproduction of between 26 and 30°C. Development fails below 25°C. according to Awati (1931). In its northern range, it may miss a year of spawning due to cold summers. *C. virginica* likewise will miss spawning for periods of several years if the temperature does not rise above 20°C. The minimal spawning temperature for *C. gigas* is also 20°C.

Cahn (1950) found that the fertilized egg of *C. gigas* was directly influenced by water temperature. The optimum temperature for the development of larvae was found to be between 23 and 25°C. The minimum temperature within which the zygote can develop to a shelled larval stage is about 25°C., and the maximum is 30°C.

According to Castillo (1907) the temperature of the water on the beds of the Chilean oyster, *O. chiloensis*, ranges from 8 to 9°C. in the winter and 15 to 16°C. in the summer. This species breeds at 15°C. or slightly less. A water temperature of 18°C. will be fatal within five hours.

Chestnut (1951) states that below 5°C., *C. virginica* ceases to function normally in its feeding and will go into hibernation. The optimum temperature for functioning of the gills is believed to be between 25 and 30°C. Pumping ceases at 40°C.

It can be seen that though oysters are capable of existing in waters where there is a wide fluctuation in temperature, they are definitely affected by minor fluctuations. Unless the water attains a temperature of at least 15 to 26°C. (depending on the species) for a prolonged period of time each year, the animals will not spawn. A continuous succession of cold summers could lead to the extinction of an entire colony. Even warmer conditions are required for the normal development of the young. The Chilean species *O. chiloensis* is an exception that must be considered when interpreting the ecology of fossil species.

In connection with oyster culture in Japan, a great deal of study has been devoted to salinity tolerances. Cahn (1950) gives the tolerances for several species common to Japanese waters. *O. circumpuncta* has a tolerance that ranges from 15 to 52 parts per thousand but the optimum salinity is between 30 and 40. *O. echinata* has a range of 18 to 49 and an optimum of 30 to 40. *O. denselamellosa* has a range of 20 to 40 parts per thousand and an optimum of 25 to 35. *O. gigas* has a range of 9 to 35 and an optimum of 20 to 30. *O. revularis* has a salinity tolerance ranging from 8 to 39 and an opti-

mum of 20 to 30. According to Amemiya (1926) the American oyster *C. virginica* has a range of 17 to 39 parts per thousand and an optimum of 25 to 30. Churchill (1919) gave the range as 2.5 to 30 and placed the optimum at 14 to 28. Hopkins (1936) placed the optimum salinity of this species above 20 and possibly as high as 30 to 35 parts per thousand. It is difficult to say which of these figures is more accurate. *O. equestris* can be found in pure sea water. There is no available information concerning the lower limit. The range for the Portugese oyster *O. angulata* is, according to Amemiya (1926), from 21 to 43 parts per thousand while the optimum is 25 to 35. The range for *O. edulis*, the English oyster, is from 24 to 45 and the optimum is from 31 to 35.

For the genus, then, the salinity tolerance ranges from 2.5 to 52 parts per thousand, and has an optimum of 20 to 40. Consequently, little can be inferred about the salinity of fossil oysters unless the relationship between the fossil and living species is well understood.

Active currents are important to oyster development because they carry diatoms, transport genital products, and provide oxygen. Currents may also serve to keep rock and shell surfaces clean of silt and algae, thus accommodating spat-fall.

The food preferred by the oyster is not known. Diatoms, copepods, free swimming larvae, worms, rotifers, and protozoa have all been found in their stomachs. Churchill (1920) believes that organic detritus resulting from the decay of plant and animal life contributes to their food.

Among the more common oyster predators are: *Polinices Urosalpinx*, *Murex*, *Eupleura*, *Fasciolaria*, and various echinoderms. All but the latter two gastropods have been reported from the Trent formation.

Family Plicatulidae

Plicatula

A recent example of this genus is *P. gibbosa* Lamarck. This species is known from North Carolina to the Gulf States and the West Indies. It inhabits beaches from the intertidal zone to just off shore.

Family Veneridae

Macrocallista

Macrocallista tia Kellum and *Callista neusensis*, two species collected from the Trent, are closely related. The most striking differences are the size and convexity of the shell; *M. tia* is larger and more convex than *C. neusensis*. A detailed statistical analysis is necessary before we can understand the relationships between these and living species of the genus. For this reason, a single modern species of each genus is considered and the group is omitted from the conclusions.

Callista eucymata Dall is known from North Carolina to Florida, Texas and the West Indies. According to Abbott (1954), it has been dredged from 25 to 110 fathoms.

Macrocallista nimbosa Solander is known from North Carolina to Florida and the Gulf coast. It is at home on sand bars and coves. *M. maculata* Linné is known from North Carolina to Florida and the West Indies. It has a habitat similar to the above species.

Venus

The genus *Venus* has recently been split into two genera. According to Wells (1957) one group is characterized by the presence of a reduced anterior lateral hinge tooth and contains mostly eastern Atlantic species. The type species is *Venus verrucosa*. The second group is characterized by the total absence of any anterior lateral hinge tooth and contains the American species *Mercenaria mercenaria* (Linné) and *M. campechiensis* (Gmelin).

The two species collected from the Trent formation appear to be closely related morphologically to *M. mercenaria*. The major difference is that the fossil forms are smaller and have a pallial sinus more rounded posteriorly than that of the living forms.

The geographical range of *M. mercenaria* is from the Gulf of the St. Lawrence to the Gulf of Mexico. It has been introduced to Humboldt Bay, California. *M. campechiensis* is known from Chesapeake Bay to Florida, Texas, and Cuba

Mercenaria lives as well in the intertidal zone as it does at depths as great as 8 fathoms.

Thorson (1957, p 461–534) states that a

Venus community is indicative of a sandy bottom. Pratt and Campbell (1956) found that the silt-clay content of the substrate or some other characteristic of fine sediment inhibits the growth of *M. mercenaria*. The greater the silt-clay percentage, the greater is the retardation of growth. This may be due to clogging of the siphons by the finer sediment, thus interrupting feeding and respiration.

Pratt & Campbell (1957) found that the mean temperature imposes a definite upper limit to the rate of growth of *M. mercenaria*. Belding (1912) found that shell growth begins when the water temperature reaches 9°C. and ceases when it falls to about 7°C. The potential growth increases as the mean temperature is raised from 9 to 23°C. There are no data concerning the rate above 23°C. Gunter (1957, p. 162) states that the upper temperature limit, above which death occurs, is 45.2°C. According to Loosanoff (1937) *M. mercenaria* will, under laboratory conditions, spawn at temperatures ranging from 23.0 to 30.2°C. Nearly all the animals that spawned below 25°C. were males. The majority of males spawned at 25 or 26°C. He was not able to induce spawning by chemical means at temperatures below 23°C.

The optimum salinity for *M. mercenaria* is from 10 to 28 parts per thousand but, extremes just below 10 and up to 35 can be tolerated.

In his study of bottom communities, Thorson (1957) discussed several *Venus* communities. These were represented by *V. fluctuosa*, *V. gallena*, *V. verrucosa*, and *V. fasciatum*. The *Venus fluctuosa* community is also referred to as the arctic Venus community because it has a circumpolar distribution. Most specimens have a vertical range of 1 to 16 fathoms but, a few have been found in the north Pacific in water as deep as 43 fathoms. This community inhabits pure sandy bottoms near the open sea. As the bottom grades from sand to silt, *V. fluctuosa* becomes less dominant and *Cardium groenlandicum* and *C. ciliatum* appear in increasing numbers.

Venus gallina communities are known in the North Sea, Inner Danish waters, the Irish Sea, English Channel, Eastern Atlantic, Mediterranean Sea, Adriatic Sea, and the Black Sea. It has a bathymetric range of 4 to 26 fathoms and prefers a sandy substrate.

V. verrucosa communities have a geographical distribution similar to *V. gallina* communities. This community is found from 5 to 150 fathoms. In shallow water it may be found on a substrate composed of shell gravel, whereas at depth it is found on sand.

Both *Venus* and *Mercenaria* prefer to live in quite swift currents. Among the predators of these genera are: *Busycon*, *Polinices*, *Murex*, and *Urosalpinx*. In general both genera inhabit waters 2 to 166 fathoms deep but are most common at depths of 5 to 26 fathoms. Both groups are restricted to sand or muddy-sand bottoms and can tolerate a wide temperature range.

Family Calyptraeidae

Calyptraea

Calyptraea centralis Conrad, formerly known as *C. candeana* d'Orbigny, is known from Hatteras to Brazil. It has a vertical range of 6 to 25 fathoms. It lives attached to other shells. *C. fastigiata* Gould is found along the Pacific coast from Alaska to Southern California. Its bathymetric range is 10 to 75 fathoms.

Crucibulum

Crucibulum auricula Gmelin is known from Florida to Brazil, in water 25 to 110 fathoms deep. *C. striatum* Say has a wide geographical range which extends from Nova Scotia to South Carolina. It may be found clinging to rocks in shallow water. *C. spinosum* Sowerby is known from Southern California to Chile. It has a vertical range of 0 to 15 fathoms.

Family Conidae

Conus

There are approximately 2700 species of *Conus* mentioned in the literature. Of these, half are fossil and many are synonyms. According to Clench (1942) *Conus* is, today, essentially a tropical genus. A few species occur in warmer portions of temperate seas, however. They are most prevalent in the Indo-Pacific region. *Conus* is found in various habitats: on mud flats, sand bars, exposed rocky coasts and reefs, as well as in

quiet lagoons and bays. The majority of the species are found just below the low tide mark to a depth of 100 fathoms but, some habituate the intertidal zone and others are found at great depth. Some North American examples are given below.

Conus mazei Deshayes is known from Cuba, the Virgin Islands and the Lesser Antilles. It has been dredged from 92 to 240 fathoms. *C. flavescens* Sowerby, known from Cape Hateras to Barbados, is found at depths of 15 to 175 fathoms. *C. stearnsi* Conrad, known from North Carolina to Florida and the Yucatan, lives in water from a few inches to 5 fathoms deep. *Conus californicus* Hinds is known from the Farallon Islands, California to lower California.

Family Melongenidae

Busycon

B. perversum Linné has a geographical range extending from Cape Hatteras, North Carolina to Cuba. It is known from the Miocene to Recent. This species is most common from very near the shoreline to water 3 feet deep. It appears to prefer a sandy bottom.

B. spiratum Lamarck ranges from Cape Hatteras to the Gulf of Mexico. It is common on sandy bottoms in shallow water.

B. canaliculatum Linne is known from Cape Cod, Massachusetts to western Florida. It occurs on all types of substrate but most commonly where it is stony. It is a shallow water species.

B. coarctatum Sowerby is known from the Yucatan area, Mexico. Abbott (1954) reports that this species is dredged by shrimp boats but he gives no specific depth. *B. carica* Gmelin is known from Cape Cod to Florida. It is common in shallow water. *B. contrarium* Conrad is known from South Carolina to the Gulf of Mexico.

Parker (1955) reports that *B. spiratum* and *B. perversum* are quite common in the Texas bays now that the salinity of these waters is normally between 20 and 40 parts per thousand. Prior to 1950, the salinities in that area ranged from 9 to 40 and prior to 1940, they were between 2 and 25. During these periods of low salinity, both species were restricted to the Gulf where the salinity is constantly near that of normal sea water. It can be seen that the optimum salinity for these species is around 25 to 35 parts per thousand.

Magalhaes (1948) reports that *B. carica*, *B. canaliculatum*, and *B. contrarium* are prevalent in the waters of Beaufort Harbor, Bogue Sound, North Carolina, where the salinity is usually 30 parts per thousand. Over a period of five years the greatest salinity was 38 and the lowest was 6. The latter occurred only once in that period and the average was near 20. The water in which these three species were collected ranged in depth from 2 to 5 feet at high tide and from 0 to 2 feet at low tide. Current flow was moderate and wave action was negligible. These species are found on sandy, shelly or muddy bottoms. A sandy mud is believed to be most suitable. The mean water temperature ranges from 7°C. in the winter to 27°C. in the summer.

Magalhaes found that in the laboratory the favorite food of these three is *Tagelus*, *Chione* and *Venus*. They have been observed in nature eating dead fish and annelids as well. The enemies of the genus are crabs, gulls and man.

In general, this is a shallow water group found in marine or slightly brackish water on various types of substrate.

Family Muricidae

Murex

According to Clench (1945) there are over 400 species of *Murex* living today. They are found in portions of temperate and all tropical seas, from a few fathoms to over 435 fathoms. They may be found on rocky, gravel or sandy bottoms. This is a carnivorous genus which feeds on pelecypods and other gastropods. Some examples follow.

Murex tryoni Hidalgo is known from Florida to Grenada and has been collected from 18 to 115 fathoms. *M. beaui* Fischer has been collected from the Gulf of Mexico and off the Florida Keys at depths ranging from 82 to 183 fathoms. *M. recurvirostris rubidus* F. C. Baker is found along the Gulf of Mexico at depths of 2 to 30 fathoms. *M. rufus* Lamarck is known from Cape Fear, North Carolina to Cartagena, Colombia. It has a vertical range of 5 to 50 fathoms. *M. santarosana* Dall is known from Santa Bar-

TABLE 2.—GENERAL ECOLOGY OF RECENT GENERA

Genus	Depth (fathoms)	Bottom	Temp.	Salinity (parts per thous.)	Currents
Arca	0–300	Varied	—	Ocean	—
Cardita	—	Varied	—	Brackish	—
Venericardia	15–124	—	—	Ocean	—
Eucrassatellites	3–100	Sand	—	Ocean	—
Diplodonta	1– 40	Sand	—	—	—
Donax	Littoral	Sand	—	Ocean	Waves to swift
Glycymeris	1–175	Sand	—	Ocean	—
Phacoides	1–100	—	—	Ocean	—
Mytilus	1–100	Varied	7–28°C.	Brackish	Swift
Ostrea	0– 22	Varied	0–32°C.	2.5–52	Swift
Venus	3–164	Sand	9–45°C.	10 –35	Swift
Calyptraea	6– 75	Varied	—	Ocean	—
Crucibulum	0–111	—	—	—	—
Conus	0–100	Varied	—	Ocean	—
Busycon	0– 2	Varied	—	20 –35	—
Murex	1–435	Sand	—	Ocean	—
Polinices	Littoral	Sand	—	Ocean	—
Sinum	—	—	—	—	Swift
Turritella	0–633	Mud & Sand	—	Ocean	—
Scaphella	1–509	—	—	Ocean	—

bara Islands to lower California. This species occurs on gravel bottoms in waters of 1 to 30 fathoms. *M. gemma* Sowerby has the same range as the above species but occurs on a rocky substrate.

Rapana

No reference can be found concerning any American species of the genus *Rapana*. Fischer (1887, p. 644) reports that many species are known in the Indian Ocean and the China Sea. He makes no reference to their ecology.

Family Naticidae

Polinices

Polinices duplicatus Say is known along the Atlantic from Massachusetts to Mexico. It lives on sand or mud flats near the open sea. According to Parker (1955) it is now found living in the Texas bays where the salinity range is from 20 to 42 parts per thousand. When the salinity in this area was between 2 and 35, this species was restricted to the Gulf of Mexico. Parker (1956. 323) found that in the East Mississippi Delta region, *P. duplicatus* was indicative of the lower sound and pro-delta slope environment. The physical characteristics of this region are as follows: variable chlorinity, a very fine silty clay to clayey silt bottom and a year round occurrence of high turbidity. A few specimens of *P. duplicatus* were also found in the upper sound and inlet environment. The inlets are characterized by tidal currents, firm bottoms of sand, sandy silty clay or shell fragments and high salinity (30 to 40 parts per thousand).

Abbott (1954) states that *P. duplicatus* is a sand lover. This conflicts with the more recent findings of Parker. The species shows a decided preference for more saline waters but appears to tolerate water with a concentration as low as 20 parts per thousand. It is a carnivorous animal feeding upon other gastropods and pelecypods.

Two other species of *Polinices* are common to North American waters. *P. lacteus* Guilding is known from North Carolina to Florida and the West Indies. It is found on sandy bottoms in the intertidal zone. *P. immaculatus* Totten is known from the Gulf of St. Lawrence to North Carolina, at depths of 1 to 25 fathoms.

Sinum

The most common Atlantic Ocean species now living is *Sinum perspectivum* Say. It is known from Virginia to Florida and along the Gulf of Mexico to the West Indies. It is common to shallow water over sandy bottoms. Parker (1955) found that this species

was restricted to the Gulf of Mexico off the Texas coast until the recent increase in salinity in the Texas bays. This indicates that it prefers waters in which the salinity is near that of normal sea water. Parker (1956, p. 335) reports *S. perspectivum* from inlets and passes characterized by strong currents.

S. maculatum Say, known from Cape Hatteras to west Florida, is a shallow water form.

Family Turritellidae

Turritella

Modern species of *Turritella* are found around the world in tropical and subtropical seas. They are, however, most abundant in the Pacific. They are found from the shoreline to depths of 640 fathoms.

Yonge (1946) states that *T. communis* Risso, a common English species, is found completely buried in mud. It may remain motionless for weeks at a time. A stiff mud is undesirable as it clogs the inhalant depression, thus hindering respiration. It is now known whether this habit is common to the genus.

T. yucaticana Dall is found in the Gulf of Mexico from shallow water to depths of 640 fathoms. *T. acropora* Dall is known from Hatteras to Grenada Island and the west coast of Florida to Texas. It has been found from 3 to 413 fathoms. *T. exoleta* Linné is known in the southern half of Florida and the West Indies. It has a depth range of 1 to 100 fathoms. *T. cooperi* Carpenter is found along the Pacific coast from Monterey, California to lower California, at depths of 20 to 40 fathoms.

Family Volutidae

Lyria

No record of American species of this group could be found. Fischer (1887, p. 610) reports the genus from the Indian Ocean, Atlantic Ocean, Pacific Ocean, and the China Sea.

Scaphella

This genus is moderately common in tropic and subtropic seas. It may be found in deep water. Abbott (1954) states that *S. junonia* Shaw is found in 1 to 30 fathoms. Clench (1946) gives no shallower depth than 15 fathoms for the upper limit of the vertical range of this species. He lists the lower limit as 45 fathoms. It is known from North Carolina to Florida and is usually found among rocks and corals.

S. dohrni Sowerby is common to the Florida Keys in waters ranging from 75 to 144 fathoms deep. *S. dubia* Broderip is known from the southern half of Florida and the Gulf of Mexico. It has a vertical range of 90 to 111 fathoms. *S. gouldiana* Dall is known from North Carolina to Florida and Cuba. It has a range of 78 to 509 fathoms.

Scaphella junonia has by far the most restricted vertical range of the genus. It is found in shallower water than any other member of this group. When this species is considered, this is a deep water genus. When it is not considered, it is a very deep water group.

CONCLUSIONS

Generally, the discussion of the ecology of the modern species of the genera collected at the new Gillette site was restricted to North American species. This was necessary as there are hundreds of species within many of the genera and to include them all would be beyond the scope of this paper. All but two, *Rapana* and *Lyria*, of the genera studied have species that may be found off the coast of North Carolina today. The majority of the genera are tropical or subtropical forms. Molluscan communities living in the waters off the coast of North Carolina are generically like that found in the Trent formation.

Twenty genera are listed on the chart. Of these, sixteen have the shallow end of their bathymetrical range in just a few fathoms of water (0 to 3 fathoms). *Calyptraea* and *Venericardia* are the only genera which have upper limits in water deeper than 6 fathoms. Since the data concerning their vertical range is meager, it is perhaps unwise to consider their shallowest limit as the likely upper limit for the fossil community. Rather, it is felt that the upper limit of the majority of the genera is more likely to be similar to that of the Trent community.

Thirteen genera have the lower limit of their vertical range at a depth greater than 100 fathoms. Six of these are greater than

158 fathoms and four are from 300 to 633 fathoms. As a great deal more study has been donated to *Ostrea* and *Venus* than to other genera, it is felt that their vertical ranges are the most accurate. Though some species of *Venus* are found in water as deep as 164 fathoms, the majority are restricted to waters less than 22 fathoms deep. *Ostrea* are restricted to waters less than 22 fathoms deep. Therefore, for the Trent community, a lower limit of between 17 and 22 fathoms can be inferred. Though the majority of the genera examined are found in water considerably deeper, none are restricted to waters much shallower than this limit.

Seven of the genera studied are known on all types of substrate, seven are restricted to sandy bottoms and one is known on sandy or rocky substrate. Consequently, judging from the animals alone, one would expect that they lived on sandy bottoms. This agrees with the field evidence as the matrix from which the shells were collected is a fine sand with clay particles also present.

Little information is available for the range in water temperature of most genera. Those best known in this respect are *Mytilus*, *Venus* and *Ostrea*. Their ranges are: *Mytilus*, 7 to 28°C.; *Venus*, 9 to 45°C.; *Ostrea*, 0 to 32°C. The upper limit for *Venus* may be a bit too high. It has been shown that several of the upper temperature limits given by Gunter are somewhat higher than those given by other authors. Of the three genera, *Venus* is much more common in the Trent. Consequently, its limits are of more concern. Since the lower limit of *Venus* is close to that of *Mytilus*, the lower limit for the Trent community can be set at 7 to 9°C. The upper limit is more difficult to determine; a high near 30°C. was probably the most usual. However extremes close to 40°C. could possibly have been tolerated.

Ostrea has been shown to spawn only when the water attains a temperature greater than 15°C. *Venus* will not spawn until 23°C. is reached. It seems likely that each year the water in which the fossils lived must have reached a temperature of at least 23°C. for prolonged periods. Any prolonged period of cold summers would have led to extinction of at least three genera *Mytilus*, *Ostrea* and *Venus*. The fact that *Venus* is one of the dominant forms in the formation indicates that conditions were close to its optimum.

Specific information concerning salinity tolerances of the majority of marine mollusks is difficult to find. In most cases, we know only that they are open sea forms. In these cases, the word "ocean" is used on the chart in the salinity column. Today, the average salinity for normal sea water is 34.325 parts per thousand, and during Trent time it must have been about the same, since eleven of the genera studied are ocean forms. In those groups where we have specific data concerning the salinity, the ranges are as follows: *Venus* from 10 to 35 parts per thousand, *Busycon* 20 to 35, and *Ostrea* 2.5 to 52. These data do not conflict with our original premise, because these three are quite capable of living under normal marine conditions. It is, of course, possible that all marine animals became adjusted to increased salinities as the salt concentration of sea water increased throughout geologic time.

Data concerning required current velocity are available in only five cases and among them it is very general. In all five, a swift current is required. Consequently, it is likely that the water flowing over the Trent beds was swiftly moving. The presence of sand in the matrix favors this opinion.

It is concluded that the ecology of the Trent fauna, as represented by the collection made during the current investigation, has some of the following characteristics. The water was very shallow to about 22 fathoms deep. The substrate was either a fine-grained sand or a sandy mud. The temperature corresponded to that of our subtropical seas, ranging between 7 and 30°C. In the summer months a temperature of 23°C. was probably normal. The salinity of the water was near that of normal sea water (34.325) parts per thousand). A swift current probably flowed over this particular shell bed.

Little can be said concerning the configuration of the basin in which the Trent was deposited until the formation has been mapped in detail and the various other faunal communities are taken into consideration. There is one interesting point to note,

however. As was mentioned earlier, *Venus fluctuosa* communities give way to *Cardium* communities as the bottoms become more silty. It is possible that this shift occurred in the Trent. At Silverdale, *Venus* is very common, but no specimens of *Cardium* have been reported. At Belgrade, both are quite common. An increase in the clay particles present in the substrate could account for this. Because the material at Belgrade has been recemented, the type of substrate for that area cannot be determined. Such an increase of mud could be caused either by deepening of the water or a slowing of the current. A large lagoon could provide such conditions. A more extensive collection of Belgrade fossils and a paleoecological study of that area could shed more light on this problem.

ACKNOWLEDGMENTS

Dr. Lewis B. Kellum, Director of the Museum of Paleontology, University of Michigan, suggested this problem and generously gave his advice on many phases of the work.

Dr. Alphonse F. Chestnut, Director of the Institute of Fisheries Research, University of North Carolina, kindly put the facilities of the instute at the author's disposal during the field investigations.

Dr. Henry van der Schalie, Museum of Zoology, University of Michigan, offered much information concerning the ecology of modern marine mollusks.

Thanks is also extended to Mr. John M. Gillette of Silverdale, North Carolina, for allowing collections to be made from marl pits on his property.

BIBLIOGRAPHY

ABBOTT, R. T., 1954, American seashells: Van Nostrand Co., New York, 541 p.

AMEMIYA, I., 1926, Notes on experiments on the early developmental stages of the Portuguese, American and English native oyster, with special reference to the effect of varying salinity: Jour. Marine Biol. Assoc., n.s., v. 14, p. 161–175.

AWATI, P. R., & RAI, H. S., 1931, *Ostrea cucullata* (the Bombay oyster): Indian Zool. Memoirs on Indian Animal Types, 111, Lucknow (Methodist Publishing House), 107 p.

BELDING, D. L., 1912, A report upon the quahawg and oyster fisheries of Massachusetts, including the life history, growth and cultivation of the quahawg (*V. mercenaria*) and observations on the set of the oyster spat in Wellfeet Bay, Boston: Weight and Potter Printing Co., 134 p.

BERRY, W. E., 1947, Marls and limestones of Eastern North Carolina: North Carolina Dept. Conserv. Devel., Div. Mineral Res., Bull. 54, p. 1–15.

CAHN, A. R., 1950, Oyster culture in Japan: U. S. Dept. Interior, Fish and Wildlife Service, Fishery Leaflet 383, p. 1–80.

CASTILLO, L., & VERGARA, Z., 1907, Apunter biologicos e industriales sobre la ostra de Chile: Ministerio de Industria, p. 1–59.

CHESTNUT, A. F., 1951, The oyster and other mollusks in North Carolina: Survey of Marine Fisheries of North Carolina, Univ. North Carolina Press, p. 141–190.

CHURCHILL, E. P., 1919, The oyster and the oyster industry of the Atlantic and Gulf coasts: Dept. Commerce, Bureau of Fisheries, app. VIII to Rept. U. S. Commissioner of Fisheries for 1919, Bureau of Fisheries Doc. 890, p. 1–51.

CLENCH, W. J., 1942, The genus *Conus* on the Western Atlantic: Johnsonia, v. 1, n. 6, p. 1–40.

——, 1945, The genus *Murex* in the Western Atlantic: *Ibid.*, v. 1, no. 17, p. 1–58.

——, 1946, The general Bathyaurina, Rehderia and Scaphella in the Western Atlantic: *Ibid.*, v. 2, no. 22, p. 1–56.

COE, W. R., & FOX, D. L., 1944, Biology of the California sea mussel (*Mytilus californianus*), III, Environmental conditions and the rate of growth: Biol. Bull., v. 87, no. 1, p. 58–72.

FIELD, I. A., 1911, The food value of sea mussels: Bull. Bureau Fisheries, v. 29, no. 742, p. 85–128.

FISCHER, PAUL, 1887, Manuel de conchyliologie et de paleontologie conchyliologique: Paris, p. 1–1359.

GUNTER, GORDON, 1951, Louisiana and Gulf Coast oysters: Science, v. 113, no. 2940, p. 516–517.

——, 1957, Temperature: Geol. Soc. America, Mem. 67, v. 1, p. 162.

HARRIS, G. D., & VAN WINKLE, K., 1919, New or otherwise interesting Tertiary mollusks from the East coast of America: Bull. Am. Paleontology, v. 8, p. 151.

HARRIS, G. D., 1919, Pelecypoda of the St. Maurice and Claiborne Stages: Bull. Am. Paleontology, v. 6, no. 31, p. 136.

HOPKINS, A. E., 1936, Adaptation of the feeding mechanism of the oyster (*Ostrea gigas*) to changes in salinity: Bull. Bureau Fisheries, v. 48, no. 21, p. 345–364.

KELLUM, L. B., 1925, The age of the Trent marl in North Carolina: Jour. Geology, v. 33, no. 2, p. 183–187.

——, 1926, Paleontology and stratigraphy of the Castle Hayne and Trent marl in North Carolina: U. S. Geol. Survey, Prof. Paper 143, p. 1–56.

——, 1931, Revision of the names of three fossils from the Castle Hayne and Trent marls in North Carolina: Jour. Washington Acad. Sci., v. 21, no. 4, p. 51–52.

LOOSANOFF, V. L., 1937, Spawning of *Venus mercenaria* (L): Ecology, v. 18, no. 4, p. 506–515.

LOTSY, J. P., 1883, The food of the oyster, clam and ribbed mussel: Report U. S. Commissioner of Fish and Fisheries for 1883, p. 375–386.

MAGALHAES, HULDA, 1948, An ecological study of snails of the genus Busycon at Beaufort, North Carolina: Ecological Mon., v. 18, no. 3, p. 377–409.

MANSFIELD, W. C., 1937, Mollusks of the Tampa and Suwanne Limestone of Florida: State of Florida Dept. Conservation and Geology Bull., no. 15, p. 1–334.

MARTIN, G. W., 1923, Food of the oyster: Botanical Gaz., v. 75, no. 2, p. 144–169.

MAURY, CARLOTTA J., 1920, Recent mollusks of the Gulf of Mexico and Pleistocene and Pliocene species from the Gulf states; Part 1, Pelecypoda: Bull. American Paleontology, v. 8, no. 34, p. 1–115.

——, 1922, Recent mollusks of the Gulf of Mexico and Pleistocene and Pliocene species from the Gulf states; Part 2, Scaphopoda, Gastropoda, Amphineura, and Cephalopoda: Bull. American Paleontology, v. 9, no. 38, p. 34–142.

MILLER, B. L., 1920, Erosion intervals in the Tertiary of North Carolina and Virginia: Bull. Geol. Soc. America, v. 20, p. 673–678.

——, 1912, The tertiary formations of North Carolina; the coastal plain of North Carolina: North Carolina Geol. Survey, v. 3, p. 174–185.

MOORE, H. F., 1897, Oysters and methods of oyster culture: U. S. Commission of Fish and Fisheries: Extracted from report of Commissioner for 1897, p. 263–340

MORRIS, PERCY, 1947, A field guide to the shells of our Atlantic coast: Houghton Mifflin Co., Boston, p. 1–190.

NELSON, THURLOW C., 1928, Relation of spawning of the oyster to temperature: Ecology, v. 9, no. 2, p. 145–154.

NEWCOMBE, CURTIS L., 1935, A study of the community relationships of the sea mussel, *Mytilus edulis* L: Ecology, v. 16, no. 2, p. 234–243.

NICOL, DAVID, 1952, A new glycymerid from the Western Atlantic: Jour. Washington Acad. Sci., v. 42, no. 8, p. 266–267.

——, 1953, A study of the polymorphic species *Glycymeris americanus:* Jour. Paleontology, v. 27, no. 3, p. 451–455.

——, 1956, Distribution of living glycymerids with a new species from Bermuda: Nautilus, v. 70, no. 2, p. 48–53.

NIKITIN, V. N., 1934, The Gudaut oyster bank (essay of ecological and fishery investigations): Trav. Station Pissicole et biologique de georgie), v. 1, no. 1, p. 51–179.

PARKER, ROBERT H., 1955, Changes in the invertebrate fauna apparently attributable to salinity changes in the bays of central Texas: Jour. Paleontology, v. 29, no. 2, p. 193–211.

——, 1956, Macro-invertebrate assemblages as indicators of sedimentary environments in the East Mississippi Delta Region: Bull. American Assoc. Petroleum Geologists, v. 40, no. 2, p. 295–376.

PEARSE, A. S., HUMM, & WHARTON, 1942, Ecology of sand beaches at Beaufort, North Carolina: Ecol. Mons., v. 12, p. 135–190.

PRATT, D. M., & CAMPBELL, D. A., 1956, Environmental factors affecting *Venus mercenaria:* Limnology and Oceanography, v. 1, no. 1, p. 2–17.

QUAYLE, D. B., 1940, The edible mollusks of British Colombia: The report of the British Colombia Fisheries Dept. for 1940; Pacific Biol. Station, Nanaimo, p. 75–87.

RICHARDS, HORACE G., 1943, Additions to the fauna of the Trent Marl of North Carolina: Jour. Paleontology, v. 17, no. 5, p. 518–526.

——, 1948, Studies on the subsurface geology and paleontology of the Atlantic Coastal Plain: Proc. Acad. Nat. Sci. Philadelphia, v. 100, p. 39–76.

——, 1950, Geology of the Coastal Plain of North Carolina: Trans. American Philosophical Society, n.s., v. 40, pt. 1, p. 19–21.

SVERDROP, H. U., JOHNSON, & FLEMING, 1942, The oceans, Prentice-Hall, Inc., p. 55.

THORSON, GUNNAR, 1957, Bottom communities (sublittoral or shallow shelf): Geol. Soc. America, Memoir 67, v. 1, p. 460–534.

TURNER, HARRY J., 1949, Report on the investigation of methods of improving the shellfish resources of Massachusetts: Prepared by the Woods Hole Oceanographic Institution, Dec. 1949; Dept. Conservation; Div. Marine Fisheries, Commonwealth of Mass., p. 1–22.

——, & BELDING, DAVID L., 1957, The tidal migrations of *Donax variabilis:* Limnology and Oceanography, v. 2, no. 2, p. 120.

WELLS, HARRY W., 1957, Status of the name *Venus:* Ecology, v. 38, no. 1, p. 160.

WEYMOUTH, FRANK W., 1920, The edible clams, mussels and scallops of California: State of California Fish and Game Commission; Fish Bull., n. 4, contr. n. 22 from the State Fisheries Lab., p. 1–72.

YONGE, C. M., 1946, On the habits of *Turritella communis* Risso: Jour. Marine Biol. Assoc. of the United Kingdom, v. 26, p. 377–380.

YOUNG, R. T., 1941, The distribution of the mussel (*Mytilus californianus*) in relation to the salinity of its environment: Ecology, v. 22, no. 4, p. 379–386.

MANUSCRIPT RECEIVED DECEMBER 3, 1958.

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 872–887, 5 TEXT-FIGS., SEPTEMBER, 1959

THE MIDDLE PLIOCENE MAMMALIAN FAUNA FROM SMITHS VALLEY, NEVADA

J. R. MACDONALD[1]
Boise, Idaho

ABSTRACT—The mammalian fauna of the Smiths Valley area, Lyon County, Nevada, is described and its relationships are discussed. The fauna includes: Leporidae gen. indet., Aplodontidae gen. indet., *?Citellus* sp., *Pliosaccomys dubius* Wilson, *Pliozapus solus* Wilson, *Peromyscus* near *antiquus*, *Dipoides* sp., Caninae gen. indet., *Osteoborus* sp., *Indarctus nevadensis* Macdonald n. sp., Felidae gen. indet., *Mammut* (*Pliomastodon*) *nevadanus* (Stock), *Pliohipppus* cf. *spectans*, *Aphelops* sp., *Prosthennops* sp., *?Pliauchenia* sp., *Paracamelus* sp., Antilocapridae gen. indet. A new name, *Paracamelus brevirostrus*, is proposed for *Megatylopus gigas* Matthew and Cook. This fauna is believed to be very close to the *Rattlesnake* fauna of Oregon in age as it contains a horse, *Pliohippus* cf. *spectans*, which may be co-specific with the Oregon species. An early Hemphillian age is also suggested by by the primitive *Dipoides*, and the camel, *Paracamelus*, from this fauna.

INTRODUCTION

THE Smith Valley fauna was first discussed by Wilson (1936) when he described a small collection of rodents from this area and introduced the faunal name. The initial collecting was done by the late Chester Stock and the late E. L. Furlong for the California Institute of Technology. Between 1931 and 1934 the area was visited by other parties from that institution and some additional material was collected.

In 1947, the late Miss Annie M. Alexander and Miss Louise Kellogg prospected the outcrops at the west end of Wilson Canyon and a few miles to the south in the Mickey Wash region. This search yielded a few beaver teeth and some badly broken bone fragments of larger mammals. In the summer of 1948, the writer with the assistance of Willis J. Pelletier and Henry T. Herlyn, prospected the area for the Museum of Paleontology of the University of California and collected most of the material described below. Subsequent short visits yielded some additional material and information on the geology of the region.

The Smiths Valley fauna was recovered from a suite of localities bordering Nevada State Highway 3 between Wilson and Central, southwest of Yerington, on either side of Wilson Canyon; along the trace of Petrified Tree Canyon; and on the north slope of the Pine Grove Hills. Access to these localities may be had by road from Yerington near the west end of Wilson Canyon. The southern portion of this area may be reached by the Mickey Canyon road which joins Highway 3 ten miles south and one mile east of Yerington. The best map of this area is the Forest Service map, "Toiyabe National Forest, Mono Division, Nevada and California," edition of 1951. A detailed description of the localities may be found on page 873.

The Smiths Valley fauna is considered as a single unit, although the material was collected from many different but associated localities. Subsequent investigation may show that this suite of specimens does not represent a single fauna, but at the present there is no evidence to the contrary.

The locality and specimen numbers refer to the paleontological collections of the California Institute of Technology (CIT) and the Museum of Paleontology of the University of California (UCMP). Comparisons with recent material were made at the University of California Museum of Vertebrate Zoology (MVZ).

[1] The writer was with the Museum of Paleontology, University of California when the major portion of this article was written.

ACKNOWLEDGMENTS

Permission to describe the material from the Smiths Valley area, in the collections of the Museum of Paleontology of the University of California, was kindly granted by Dr. R. A. Stirton who also greatly assisted in the preparation of this report. The field

work was made possible through the generosity of the late Miss Annie M. Alexander. The help of Messers. Charles Ragsdale of Cottonwood Ranch, and Sumner Hatch of Yerington was of immeasurable value during collecting operations. The figures with the exception of the locality map were made by Owen J. Poe. The able field assistance of Willis J. Pelletier and Henry T. Herlyn is greatly appreciated.

THE AGE OF THE SMITHS VALLEY FAUNA

The fauna from Smiths Valley, is considered to be early Hemphillian in age, and a correlative of the Rattlesnake fauna of Oregon. This correlation is based on the horse *Pliohippus* cf. *spectans* which closely resembles *Pliohippus spectans* (Cope) from the Rattlesnake fauna, and on the stage of development of the *Paracamelus* from this area. The beaver, *Dipoides* sp., is a very primitive species of this genus as is shown by the presence of roots on the cheek teeth.

Wilson (1936 and 1937) suggested that the fauna might be equivalent to the Thousand Creek fauna from Northwestern Nevada. However, with the additional material that is now available an earlier age is indicated.

DESCRIPTION OF LOCALITIES

The Smiths Valley localities are in Lyon County, Nevada. The Museum of Paleontology localities are plotted on the locality map (text-fig. 1) as accurately as possible for a map of this scale; the California Institute of Technology localities may be approximate only as they were plotted from the locality descriptions. The entire area is covered by aerial photographs which were made for the Soil Conservation Service, and the major drainages are covered by an excellent series of photos prepared by the Department of the Army, Corps of Engineers.

CIT Loc. 173.—3.67 miles S 19° W from the summit of Mount Wilson.

CIT Loc. 174.—3.12 miles due south of Mount Wilson.

CIT Loc. 175.—4.25 miles S 9° E from the summit of Mount Wilson.

CIT Loc. 176.—5.87 miles S 16° E from the summit of Mount Wilson.

CIT Loc. 177.—2.40 miles S 11° W from the summit of Mount Wilson.

V4713, Mickey Wash, Site 1. In small basin; SW¼, sec. 3 and NW¼, sec. 10, T. 10 N., R. 25 E., in a series of tuffs, paper shales, and clays.

V4714, Mickey Wash, Site 2. In next basin west of V4713; SE¼, sec. 4, and NE¼, sec. 9, T. 10 N., R. 25 E.; stratigraphically above V4713; water-lain tuffs interbedded with cliff forming sandstones; separated from Site 1 by ridge of Quaternary alluvium.

V4715, Smiths Valley. At west end of Wilson canyon in a series of tuffs and sands. Exact locality unknown.

V4839, High Ridge. Three-fourths of a mile south of Wilson Canyon in Petrified Tree Canyon; NE¼ of the SW¼, sec. 20, T. 11 N., R. 25 E.; top of first large spur extending into the canyon from the east; interbedded sands and tuffs.

V4840, Lower Petrified Canyon. One mile south of Wilson Canyon in Petrified Tree Canyon on small spur one-fourth mile south of High Ridge on east wall of canyon; SE¼, sec. 20, T. 11 N., R. 25 E., sands and clays at same stratigraphic level as V4839.

V4841, Upper Petrified Canyon. Two miles south of Wilson Canyon and just south of an andesite breccia dike that dams canyon one and one-half miles south of its mouth on the West Walker River; S½, sec. 29, T. 11 N., R. 25 E.; in a series of blue sands, pebbly conglomerates, and gray tuffs.

V4842, Mickey Wash, Site 3. Next basin west of V4714; SW¼, sec. 4, SE¼, sec. 5, E½, sec. 8, and W½, sec. 9, T. 10 N., R. 25 E.; stratigraphically higher than V4714; in a series of tuffs, pebble conglomerates, and blue sands with brown shale members.

V4843, Mount Wilson. One-half mile northwest of the West Walker River highway bridge at the west end of Wilson Canyon; NE¼, sec. 18, T. 11 N., R. 25 E.; gray limonitic sands and tuffaceous shales; although the area is badly faulted the beds appear to be at the same stratigraphic level as the exposures on High Ridge.

V4853, Mickey Wash, Site 4. One mile south of Mickey Wash, Site 1; in a series of tuffs, shales, and sands; steeply tilted to the north by the upthrust of the Pine Grove Hills; these beds seem to be the stratigraphic equivalents of the beds exposed at V4713.

THE MAMMALIAN FAUNA OF THE SMITHS VALLEY AREA

LAGOMORPHA

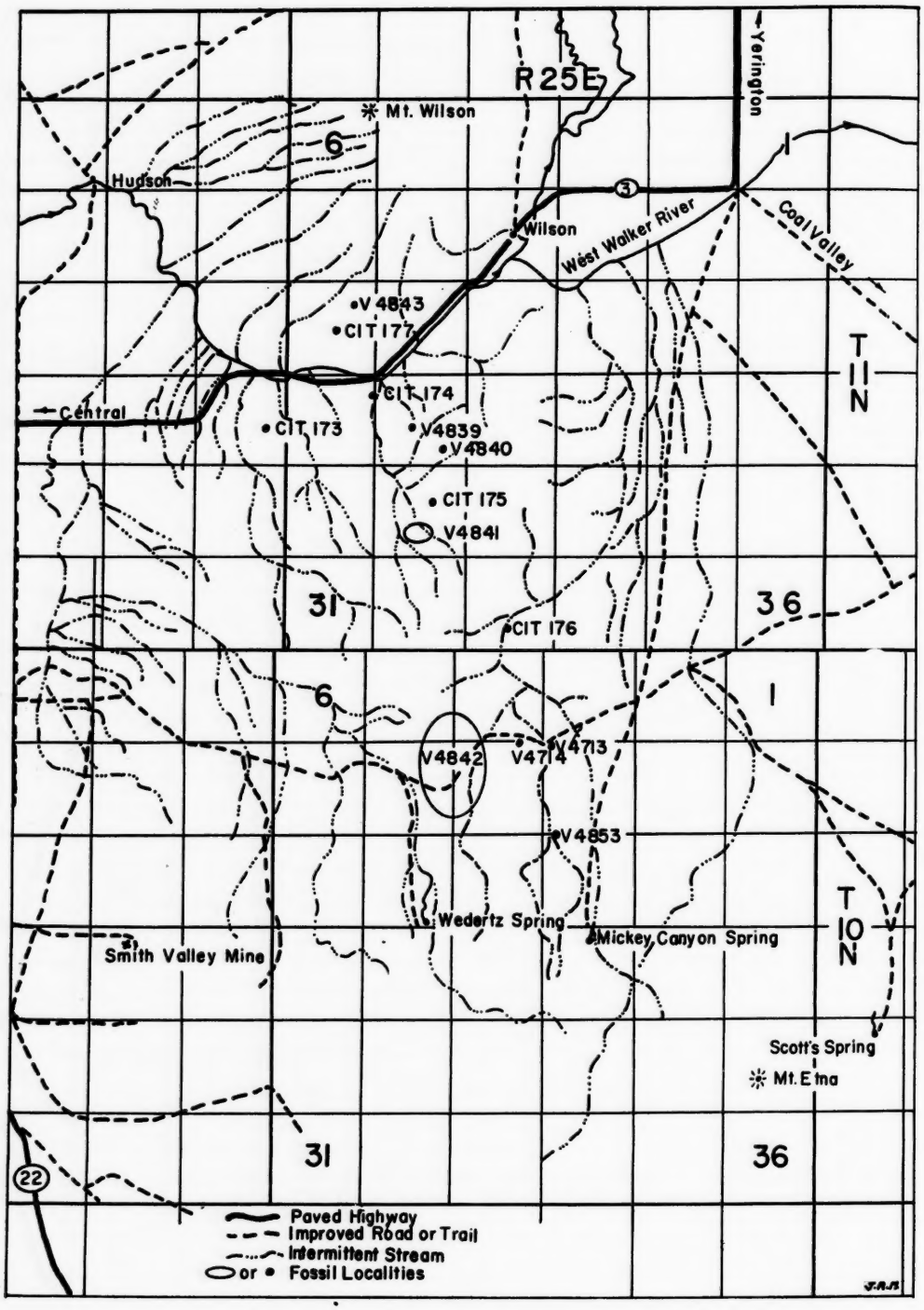
LEPORIDAE, gen. indet.

Locality and specimen.—CIT 174, Smiths Valley. A lower left cheek tooth. Described by Wilson (1936, p. 34).

RODENTIA

APLODONTIDAE gen. indet.

Locality and specimen.—CIT 174, Smiths Valley. Outer half of a left P^4, CIT 1793. Described by Wilson (1936, p. 18–19).



TEXT-FIG. *1*—University of California and California Institute of Technology fossil localities in the Smiths Valley area, Lyon County, Nevada.

SCIURIDAE
?CITELLUS sp.

Locality and specimens.—CIT 174, Smiths Valley. A right lower jaw without teeth, CIT 1795, and a fragment of a left ramus with M_2, CIT 1794. Described by Wilson (1936, p. 19–20).

GEOMYIDAE
PLIOSACCOMYS DUBIUS Wilson

Locality and specimens.—CIT 174, Smiths Valley. A right ramus with P_4–M_3, CIT 1796; a skull fragment, CIT 1797; a palatal fragment with right P^4-M^2 and left P^3–M^1, CIT 1798; and miscellaneous jaw and maxillary fragments. Described by Wilson (1936, p. 20–29, pl. 1, figs. 1–8, pl. 2, figs 1,2,2a,5, and 6).

Castoridae
DIPOIDES sp.
Text-fig. 2

Locality and specimens.—V4713, Mickey Wash, Site 1. Maxillary fragment with P^4–M^1, UCMP 38773; $M?^3$, UCMP 39337; P_4, UCMP 39335 and 39336; and a mandibular fragment with P_4–M_2, UCMP 38767.

The small collection of beaver teeth from Mickey Wash was started by the late Miss Annie M. Alexander and Miss Louise Kellogg. These teeth seem to be those of a primitive *Dipoides*.

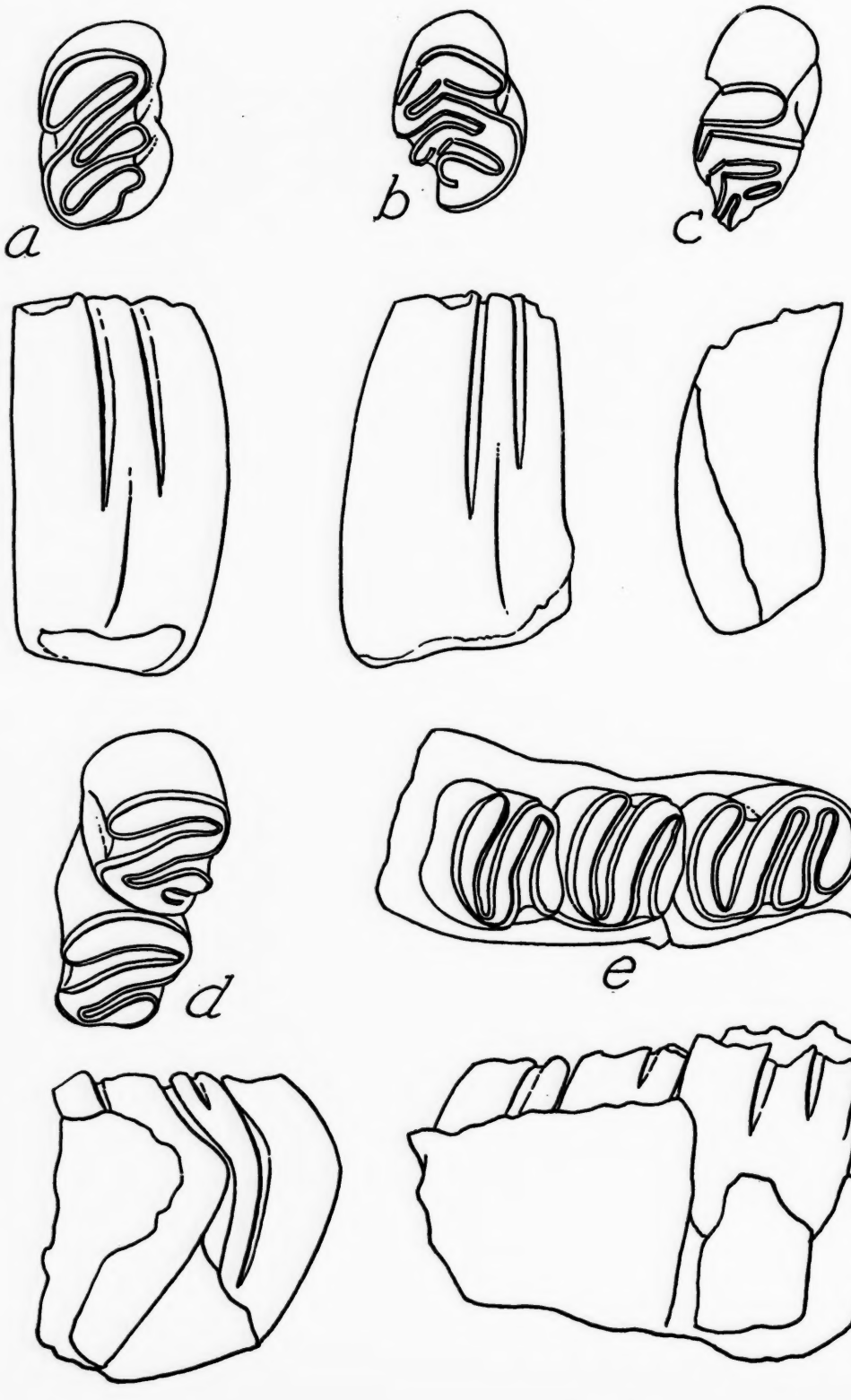
P^4 is represented in the maxillary fragment (UCMP 38773); although partially crushed the occlusal pattern is distinct. The occlusal surface is 10.2 mm. above the base of the enamel, the greatest length of the occlusal surface is 5.2 mm.; there is no parafossette on the paraflexus; the hypoflexus is long and narrow; extending to the labial enamel border; the mesoflexus is narrow, not strongly crescentic, and does not extend to the lingual enamel border; the length of the hypostria cannot be determined; the metaflexus is short, 1.0 mm., and narrow with a remnant of the base of a fossette adjacent to its tip; the presence of a root is not determinable. The M^1 in the same maxillary is also partially crushed. The "S" pattern would be persistent throughout the greater length of the tooth; the mesostria extends to within 3.4 mm. of the base of the enamel; the total length of the tooth at the present stage of wear is approximately 10.3 mm.; the presence of a root is not determinable.

An isolated upper molar (UCMP 39337), is probably a M^3 which has been badly crushed. The inflections are long and narrow as in the other molars; the metaflexus is present with a small fossette between its tip and the enamel of the labial border; the parafossette or paraflexus appearently is not present; the labial side of the tooth is broken so that the length of the mesostria and the metastria are not determinable; the root has either been broken off or is not present.

The P_4 is known from two isolated teeth (UCMP 39335 and 39336), and one in a mandibular fragment (UCMP 38767). The narrow paraflexid is gently curved anteriorly in early stages of wear, and nearly straight in the more heavily worn teeth; the mesoflexid is slender and narrow labially; it is longer in the later wear stages, there is no indication of a metaflexid or metafossettid; the parastriid and the mesostriid extend to within 2.1 mm. of the base of the enamel, except in UCMP 38767 in which the mesostriid is 1.5 mm. from the base of the enamel; the hypoflexid does not terminate against the enamel on the lingual side of the tooth; the root is present in UCMP 38767.

M_{1-2} are in the same mandible (UCMP 38767). These teeth are worn; the "S" pattern continues through most stages of wear; the inflections are long and narrow, the hypoflexid abutts against the enamel on the lingual side of the tooth but the mesoflexid does not; the mesostriid probably extends to within 1.2–2.0 mm. of the base of the enamel; the four sides of the tooth are nearly equilateral.

The closure of the roots in the well worn specimens from Mickey Wash indicates that these teeth represent a very primitive *Dipoides*, which is little advanced over the late Clarendonian species *Eucastor lecontei* (Merriam) from the Pacific Coast and with the closely related species from the correlative faunas at the Nightingale Road (Macdonald, 1956) and Chalk Spring (Macdonald, 1949) localities in the Truckee and Humbolt formations. On the basis of available material it most closely resembles *D. stirtoni* Wilson (1934) from the Rome fauna of Oregon.


a
b
c
d
e

CRICETIDAE

PEROMYSCUS near ANTIQUUS

Locality and specimen.—CIT 174, Smiths Valley. A left ramus with M_{1-3}, CIT 1812. Described by Wilson (1936, p. 33–34, pl. 2, figs. 3, 3a).

Wilson (1936, p. 18 and 1937, p. 67) pointed out the similarity of this specimen to the material from the Thousand Creek fauna. It might be added that D. F. Hoffmeister (in Macdonald, 1949, pp. 178–9) described a jaw fragment of *Peromyscus antiquus* Kellogg from the late Clarendonian Chalk Spring fauna in northeastern Nevada.

ZAPODIDAE

PLIOZAPUS SOLUS Wilson

Locality and specimen.—CIT 174, Smiths Valley. A right ramus with M_{1-3} (CIT 1811). Described by Wilson (1936, p. 29–33, pl. 2, figs. 4,4a).

CARNIVORA

CANIDAE

CANINAE gen. indet.

Locality and specimen.—V4853, Mickey Wash, Site 4. A jaw fragment without teeth, UCMP 38780.

A fragmentary lower jaw with the alveoli of I_{1-3} and the roots of the canine and the four premolars. This animal was larger than a large fox and smaller than a coyote. The incisors were crowded and the premolars widely spaced; the first premolar was single rooted and the remainder unreduced.

OSTEOBORUS sp.

Locality and specimen.—V4853, Mickey Wash, Site 4. A fragment of a maxillary. UCMP 38778.

A small fragment of a left maxillary with the posterior portion of the alveolus of the canine, the alveolus for a single rooted P^1, and moderately worn P^2 and P^3. The size and position of the premolars is the same as that of *Osteoborus cynoides* (Martin) from the Hemphill of Texas. These teeth are more crowded than the average dentition of the early Pliocene species, *Osteoborus diabloensis* Richey (Macdonald, 1948, p. 61–68, figs. 5 and 7).

Although this maxillary is similar to *O. cynoides* (Martin) I hestitate to make a specific determination on the basis of such a poor specimen. It should be noted that the shortening of the rostrum is equal to that of the Texas species.

Comparative Measurements of *Osteoborus*

	Osteoborus sp. UCMP 38778	*O. cynoides* UCMP 30476
P^1, alveolus, antero-posterior diameter	4.8	4.5
P^1, alveolus, transverse diameter	4.5	4.6
P^2, greatest antero-posterior diameter	8.5	8.2
P^2, greatest transverse diameter	5.0	4.2
P^3, greatest antero-posterior diameter	10.0	11.3
P^3, greatest transverse diameter	5.8	6.4

URSIDAE

INDARCTOS NEVADENSIS Macdonald n. sp.
Text-fig. 3

Type.—Right mandible, UCMP 38629. Mandibular ramus with canine, P_{1-4}, and M_1 and the alveoli for I_{1-3}, M_2, and M_3.

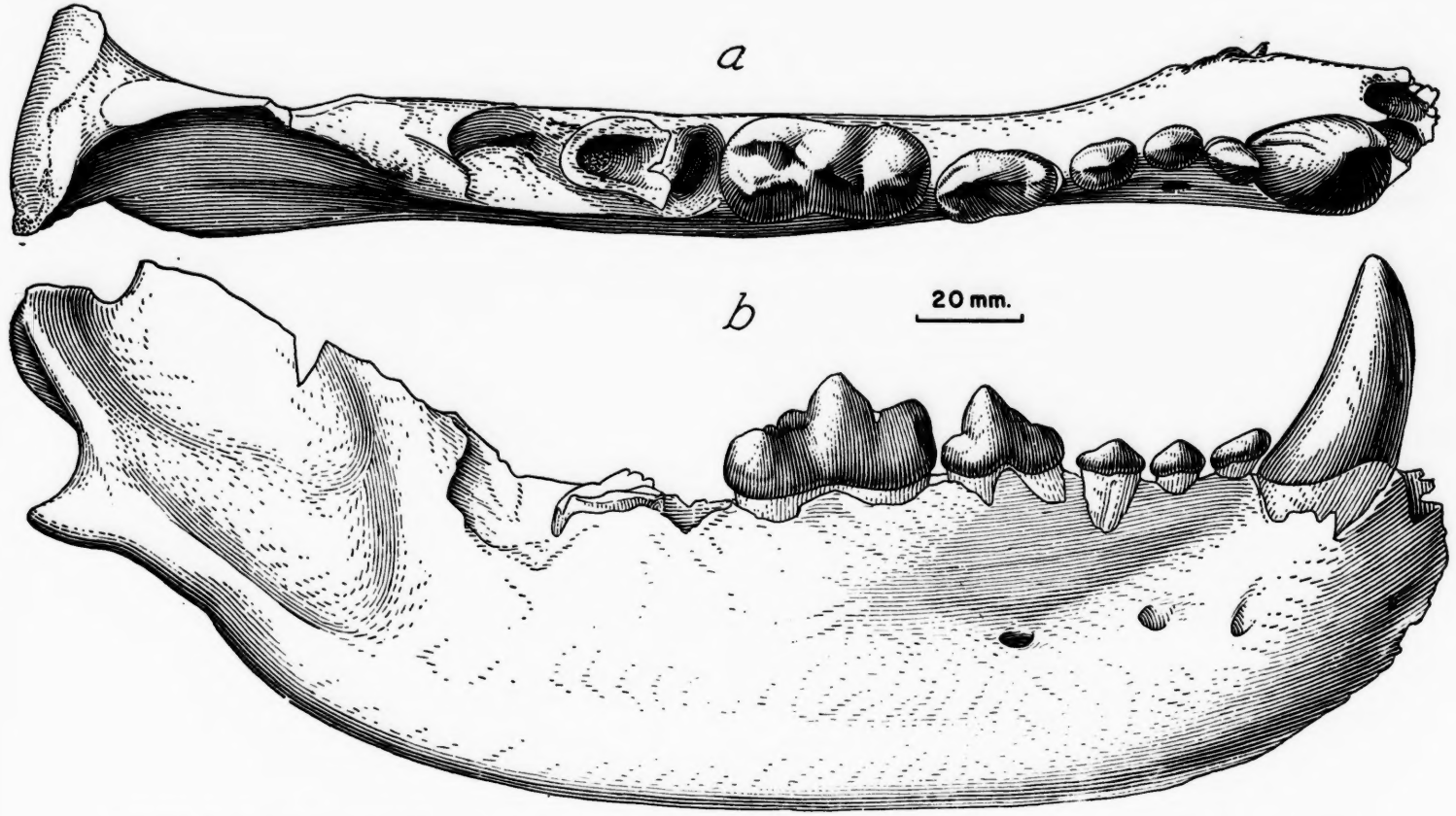
Type locality.—U. C. Mus. Pal. Loc. V4841, Upper Petrified Canyon.

Fauna.—Smiths Valley.

Age.—Middle Pliocene, Hemphillian.

Diagnosis.—Mandible large; incisors crowded; canine long with anterior and posterior lingual trenchant crests; P_3 with deeply grooved single root; P_4 separated from M_1, posterior cingulum and cusp strongly developed; M_1 with trigonid nearly

TEXT-FIG. 2—*Dipoides* sp. *a*, P_4 U. C. Mus. Pal. No. 39335; *b*, P_4, U. C. Mus. Pal. No. 39336; *c*, $M?^3$ U. C. Mus. Pal. No. 39337; *d*, P^4–M^1, U. C. Mus. Pal. No. 38773; *e*, P_4–M_2 inclusive, U. C. Mus. Pal. No. 38767. Occlusal and lingual views of lower teeth, occlusal and labial views of upper teeth. ×4.



TEXT-FIG. 3—*Indarctus nevadensis*, n. sp., Holotype, right lower jaw; *a*, occlusal view; *b*, labial view. U. C. Mus. Pal. No. 38629.

as wide as talonid, trigonid bluntly rounded anteriorly, talonid broadly rounded, entoconid small, post-entoconid cusp equal in size but lower.

Description.—Dentition unworn; alveoli for incisors elongated antero-posteriorly, tightly appressed; canine long, slightly recurved with anterior and posterior lingual ridges. P_{1-3} single cusped with antero-posterior medial crest; P_3 with deeply grooved single root. P_4 oriented parallel to main axis of ramus; tilted slightly posteriorly, anterior cusp reduced, posterior cusp well developed; cingulum on anterior lingual corner and around talonid. M_1 with talonid slightly wider than trigonid, talonid bulbous; cingulum faintly indicated on anterior lingual corner and labial side; paraconid and protoconid separated by shallow carnassial notch with deeply rounded lingual face; metaconid in posterior position; talonid basined; entoconid much smaller than metaconid; post-entoconid cusp equal to entoconid in size, in lower position; hypoconid eqal to metaconid with small intraprotoconid-hypoconid cusp. M_2 represented by anterior alveolus and posterior root; antero-posterior diameter at least three-fourths antero-posterior diameter of M_1. M_3 represented by broken alveolus only. Mandible uniformly curved on ventral border, except for offset under center of massateric fossa, angular process prominent, expanding posteriorly; three post-canine mental foramina; no masseteric fossa.

Discussion.—This species is most closely allied to *I. lagrellii* Zdansky and *I. sinensis* Zdansky (1924). The former species is smaller, and the latter is equal in size to the Nevada species. In addition to its greater size, *I. nevadensis* differs from *I. lagrellii* in having a greater crowding of the incisors; a well developed posterior cusp and cingulum on P_4; and M_1 has a relatively larger trigonid with the entoconid smaller than the metaconid.

I. sinensis is about the same size as *I. nevadensis* but differs in having a relatively narrower trigonid which tapers anteriorly as it does in *I. lagrellii.* The intraprotoconid-hypoconid cusp is larger and more prominent.

A comparison with *I. oregonensis* Merriam, Stock, and Moody (1916) shows that the upper teeth of the Rattlesnake species have the proper proportions to occlude with the lowers of the Nevada species. However, the canine of *I. oregonensis* is quite different from that of *I. nevadensis* in that it is very short crowned with an extremely massive root, unlike the long slender canines found in the two Chinese species and that from Nevada. A second series of upper teeth from the Rattlesnake fauna is similar to *I. sinensis,* but differ in having but a single cusp on the talon of P^4. These teeth are too small to be referable to *I. nevadensis.*

I. punjabensis (Lydekker, 1878) from the Middle Siwaliks is not as closely related to this new species as are the two Chinese forms. The figured specimen shows only three lower premolars with the second missing. The trigonid of M_1 tapers anteriorly as it does in the closely related genus *Lyderrerion,* and the talonid becomes reduced in width behind the metaconid.

The European *Indarctos arctoides* (Deperet, 1895) from Montredon has an anteriorly tapered trigonid on M_1 and the carnassial notch is more deeply indented laterally. The entoconid is more prominent.

Indarctus atticus (Dames, 1883) from the Island of Pikermi is illustrated (Weithofer, 1888) by a very crude sketch. The carnassial is worn or broken nearly to the alveolar border and, from the illustration, is specifically indeterminate. The alveolus for M_3 appears to be much more rounded than that of *I. nevadensis.*

I. maraghanus (Mecquenem, 1925) from the Haragha of Persia has a very prominent anterior cusp on P_3. M_1 has an anteriorly tapered trigonid and the carnassial notch is more deeply indented laterally.

I. salmontanus (Pilgrim, 1913) is another Indian species with a tapered trigonid on the M_1.

The above comparisons show that the Nevada species is closer to the Chinese forms that to those from India and Europe. It is no more specialized than the Chinese species, and represents an emigrant from northeastern Asia which has changed little during its isolation. General discussions on this genus and closely related forms may be found in Frick (1926), Matthew (1929), and Pilgrim (1931).

COMPARATIVE MEASUREMENTS OF *INDARCTOS*

	I. nevadensis No. 38629	*I. lagrellii* (after Zdansky)	*I. sinensis* (after Zdansky)
Canine, antero-posterior diameter	26.5		27.8
Canine, transverse diameter	20.1		19.3
P_1, antero-posterior diameter	12.1	10.4	11.1
P_1, transverse diameter	7.5	7.0	7.4
P_2, antero-posterior diameter	11.9	9.2	8.9
P_2, transverse diameter	8.1	6.4	7.8
P_3, antero-posterior diameter	12.7	12.5	
P_3, transverse diameter	9.1	8.3	
P_4, antero-posterior diameter	23.5	21.5	
P_4, transverse diameter	14.7	12.0	
M_1, antero-posterior diameter (est.)	40.5	37.5	42.8
M_1, transverse diameter trigonid	17.8	20.8	21.4
M_1, transverse diameter talonid	20.6		
M_2, antero-posterior diameter, alv.	31.4		

?INDARCTOS sp.

Locality and specimen.—CIT 174, Smiths Valley. A right metacarpal II, CIT 793.

This foot bone from a large bear is possibly referable to *Indarctos*. It is quite large but smaller than that of *Ursus kenaiensis* Merriam from the Kenai Peninsula, Alaska, with which it was compared. metacarpal II, is much larger and more massive than its counterpart in the Texas collections. The greatest lateral width at the distal end of this specimen is 23.5 mm., the greatest antero-posterior diameter is 22.2 mm. The comparable measurements of a specimen of *M. catocopis* (UCMP 30192) are 17.2 and 18.3.

COMPARATIVE MEASUREMENT OF *?INDARCTOS* SP. AND *URSUS KENAIENSES*

	?Indarctos sp. CIT 793	*Ursus kenaienses* MVZ 4725
Greatest length	91.3	92.4
Greatest antero-posterior diameter at distal end of keel	19.3	22.9
Greatest lateral diameter on distal end	18.6	20.8
Greatest lateral diameter at proximal end	16.7	19.8
Greatest antero-posterior diameter at proximal end	27.7	33.5

Locality and specimens.—V4714, Mickey Wash Site 2. Two complete proximal phalanges, the proximal half of a proximal phalanx and a median phalanx, UCMP 38625 and 38768.

This material is of comparable size with the metacarpal II from CIT 174.

FELIDAE gen. indet

Locality and specimens.—CIT 175, Smiths Valley. Distal portions of two metapodials, unnumbered.

These metapodial fragments are similar to those of *Machairodus catocopis* Cope (1887) although somewhat larger and more massive.

One specimen is questionably identified as a metatarsal IV and is within a millimeter of being as large as a *M. catocopis* specimen from the Hemphill fauna, and the other, which is tentatively identified as a right

PROBOSCIDEA

MAMMUTIDAE

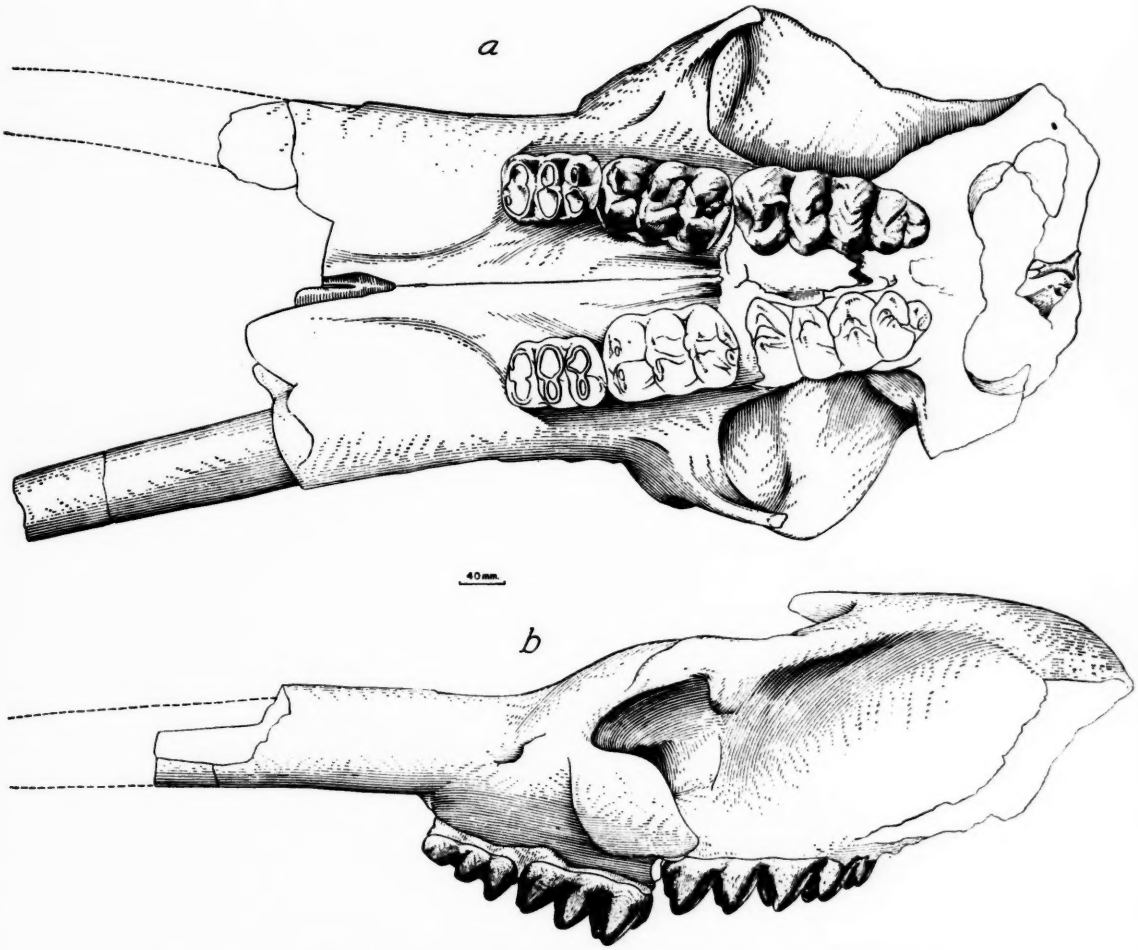
MAMMUT (PLIOMASTODON) NEVADANUS (Stock)

Text-fig. 4

Locality and specimen.—V4841, Upper Petrified Canyon. A cranium, UCMP 38645.

A fine cranium referable to Stock's (1936) species from the Thousand Creek beds of northwestern Nevada was found by Mr. Herlyn in 1948 in the Upper Petrified Canyon area. The specimen was in good condition, although suffering from the attacks of sagebrush roots.

The upper tusks are short and without enamel; M^1 has three lophs, faint double lingual trefoils, no conules, and the talon is greatly rreduced. The M^2 also has three lophs; there are double lingual trefoils which



TEXT-FIG. 4—*Mammut* (*Pliomastodon*) *nevadanus*, cranium,-*a*, palatal view; *b*, view of left side. U. C. Mus. Pal. No. 38645.

COMPARATIVE MEASUREMENTS OF *MAMMUT* (*PLIONASTODON*) *NEVADANUS*

	CIT 1922 (Type)	UCMP 38645	*M.* (*P.*) *adamsi* (Hibbard) after Hibbard
M^1, greatest antero-posterior diameter		90.0	
M^1, greatest transverse diameter at the third loph		65.7	
M^2, greatest antero-posterior diameter	112.0	115.0	100.6
M^2, greatest transverse diameter	71.7	77.5	77.5
M^3, greatest antero-posterior diameter	155.6	179.0	179.0
M^3, greatest transverse diameter	76.0	80.0	86.0
Width of the tusks at alveolar opening		68.0	
Length of cranium along midline from lambdoidal crest to anterior edge of premaxillary		890.0±	
Width between tips of postorbital process		478.0±	
Width of rostrum at anterior edges of M^1		300.0±	
Width of rostrum at alveolar edge of tusks		347.0±	
Width of palate between inner edges of anterior lophs of M^1		107.0±	
Width of palate between inner edges of anterior lophs of M^2		77.0±	

are reduced in the first valley and larger in the second valley; the talonid is small. The M^3 has four and one-half lophs; the first loph has a reduced posterior lingual trefoil, the second loph has a reduced anterior lingual trefoil and a large posterior lingual trefoil, the third loph has only a large anterior lingual trefoil, the fourth loph is reduced to two small cusps and is intermediate in width between the third and fifth lophs, the fifth loph is very small being formed by two small cusps. The valleys between the lophs are open.

In general shape and size this specimen does not differ greatly from the type specimen from Thousand Creek. The measurements of the third molar in the accompanying table are approximate, as the tooth had not completely erupted at the time of the animal's death.

GOMPHOTHERIIDAE, gen. indet.

Locality and specimens.—V4853, Mickey Wash, Site 4. Several fragmentary teeth.

These fragments are generically unidentifiable but show a strong development of a single trefoil.

PERISSODACTYLA
EQUIDAE
PLIOHIPPUS cf. SPECTANS
(Text-fig. 5)

Localities and specimens.—V4713, Mickey Wash Site 1. UCMP 38770, 38765. V4714, Mickey Wash Site 2. UCMP 38648, 38649. V4715, Smiths Valley. UCMP 38766. V4839, High Ridge, UCMP 38618, 38627, 38776, 38625, 39322, 39324. V4843, Mount Wilson. UCMP 38708. CIT 177, Smiths Valley. Unnumbered.

Although these *Pliohippus* teeth were found scattered throughout the various Smiths Valley localities, they are treated as a unit due to the similarity of character which seemingly indicates that they represent a single species. The unnumbered CIT specimen is an upper cheek tooth which is so badly worn that it indicates only the presence of this genus at Locality 177.

Two right upper deciduous premolars (UCMP 38627) from High Ridge are very similar to those of *P. interpolatus* (Cope) from the Hemphill of Texas; but similar patterns can be seen in the milk teeth of several different species of *Pliohippus*.

A right P^4 (UCMP 38765) is slightly smaller antero-posteriorly than the type of *P. spectans* (Cope) which was figured by Osborn in 1918. The hypocones and protocones are similar and the pre- and postfossettes have the same pattern, although in the Nevada specimen the fossettes are joined.

An upper right premolar (UCMP 38766) is somewhat smaller and has a small preprotoconal groove breaking into the prefossette, the pattern of the hypocone and protocone are the same as in UCMP 38765, both are rounded and pinched in on the labial side.

Two upper right molars (UCMP 38648 ans 38776) closely resemble some topotypal material of *Pliohippus spectans* in both occlusal pattern and curvature of the crown.

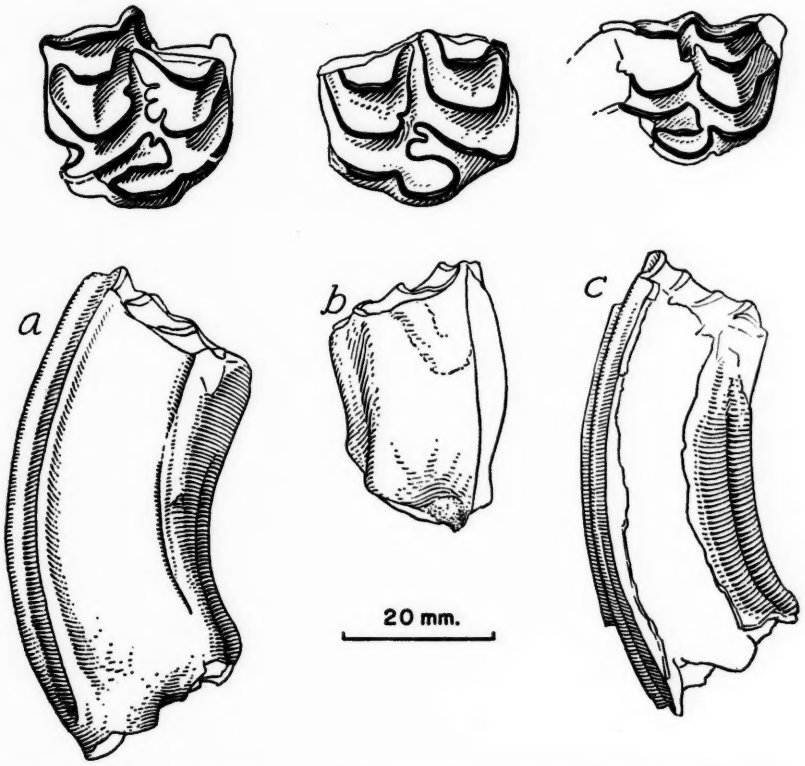
Three strongly curved M^3's (UCMP 38618 and 38625) are smaller in occlusal dimensions and more sharply tapered posteriorly than their counterparts in *P. spectans*.

Two *Pliohippus* M_3's (UCMP 38908 and 38649) may belong to the same species, but they are not diagnostic.

This collection of teeth, when considered as a unit, falls within the general range of variation found in the early Hemphillian species of *Pliohippus*. The crown height and curvature of the unworn upper third molars are greater than in the older Clarendonian species *P. pernix* (Marsh) from the Big Spring Canyon fauna, and less than in *P. interpolatus* (Cope), from the Hemphill, although the curvature of the teeth may fall within the range of variation of the latter species.

A comparison with other species shows that the curvature of these teeth is less than in *P. robustus* (Marsh), and that the enamel pattern is not as complex. *P. tantalus* (Merriam), from the Ricardo, has more complicated fossette borders. *P. fairbanksi* (Merriam) from the same fauna (considered a synonym of *P. tantalus* (Merriam) by Stirton, 1940, p. 192), has a very short hypoconal groove which disappears at an early stage of wear, in contrast to the persistent groove in the Smiths Valley form.

Pliohippus edensis (Frick) from southern California has a similar enamel pattern, but seemingly less curvature. *P. tehonensis* (Merriam) has the same curvature and an equally long hypoconal groove, but the



TEXT-FIG. 5—*Pliohippus* cf. *spectans*, *a*, upper cheek tooth, U. C. Mus. Pal. No. 39322; *b*, upper cheek tooth, U. C. Mus. Pal. No. 39324; *c*, M^3, U. C. Mus. Pal. No. 38618. Occlusal and posterior views.

fossettes are more compressed anteroposteriorly. *P. coalingensis* (Merriam) from the Etchegoin has a much straighter crown, and *P. leardi* Drescher from the Chanac may be distinguished by the transverse compression of the fossettes.

In view of the above comparisons, it would appear that these specimens represent a form which is more closely related to *Pliohippus spectans* (Cope) of the Rattlesnake fauna. If not the same species, it is so close that a similar age is indicated.

RHINOCEROTIDAE
APHELOPS sp.

Locality and specimen.—CIT 174, Smiths Valley. A metacarpal II, Unnumbered.

This metacarpal with a total length of 141 mm. is referable to this genus.

RHINOCEROTIDAE gen. indet.

Locality and specimen.—V4841, Upper Petrified Canyon. A fragmentary ramus, UCMP 38640.

The fragmentary right ramus of a juvenile rhinoceros has the alveoli for the I_3, canine, and the small single rooted P_1, the P_2 is slightly worn but nearly complete, the P_3 is broken, and the large alveolus for the P_4 is partially represented.

This jaw closely resembles a juvenile ramus (UCMP 30090) from the Clarendon of Texas, which was found in association with abundant *Teleoceras* material.

ARTIODACTYLA
TAYASSUIDAE
PROSTHENNOPS sp.

Locality and specimens.—V4839, High Ridge. Fragmentary palate, UCMP 38611; two jaw fragments, UCMP 38626. V4713, Mickey Wash, Site 1, Miscellaneous cheek teeth, UCMP 38792.

A fragmentary palate (UCMP 38611)

containing the left P^{2-3} and the roots of the same teeth on the right side was found in association with a number of fragmental skeletal remains of a juvenile *Prosthennops*. The P^2 is triangular in shape with its greatest antero-posterior diameter (9.2 mm.) only slightly greater than its greatest transverse diameter (8.8 mm.); there are three cusps, the anterior one the largest, the lingual-posterior cusp somewhat smaller, and the labial-posterior cusp is the smallest. The P^3 has two large anterior cusps and a smaller posterior-labial cusp: the posterior-lingual corner is worn down but the presence of two small cuspules is indicated.

The teeth of this specimen do not differ greatly from those of *Prosthennops oregonensis* Colbert (1938) from the Rattlesnake fauna. His species is characterized by the presence of a triangular shaped second upper premolar. Merriam (1911) and Colbert (1938) also report a second upper premolar from the Thousand Creek fauna with a triangular outline and of a similar size. However, this tooth has only one well developed cusp.

Two lower jaw fragments (UCMP 38626), one containing the roots of P_2 and P_3 the other with the roots of P_3–M_1, a median phalanx, the badly weathered fragments of some podials, and the distal end of a metapodial were also found on High Ridge. This material represents an animal that was smaller than *P. oregonensis*. Its association with the material described above indicates that it probably is a variant of the same form.

Fragmentary peccary remains were also found at V4714, Mickey Wash Site 2 (UCMP 38654), V4843, Mount Wilson (UCMP 38709), and at CIT 175, Smiths Valley (Unnumbered).

Camelidae

?Pliauchenia sp.

Locality and specimen.—V4853, Mickey Wash Site 4. Fragment of a left maxillary, UCMP 38773.

This fragmentary left maxilary has the double alveolus for the dP^3 and a slightly worn dP^4 and M^1. It resembles a specimen from Big Spring Canyon (UCMP 29543) which Gregory (1942) referred to *Pliauchenia*. The teeth of the Nevada specimen are higher crowned and have a relatively and actually greater antero-posterior diameter.

Comparative Measurements of ?*Pliauchenia* sp.

	UCMP 38773	UCMP 29543
dP^3, antero-posterior diameter of alveolus	13.5 est.	10.2
dP^4, antero-posterior diameter	31.8	25.3
M^1, antero-posterior diameter	34.5	27.4

Paracamelus brevirostrus n. name

The relationship of the large Hemphillian and Blancan camels is not adequately understood, and there is much confusion in the literature. Matthew came to the conclusion that some of these large camels in North America were referable to the genus *Paracamelus* Schlosser, but he did not discuss the matter in print. It is now fairly well understood that the large camels in these faunas, previously called *Pliachenia*, are not referable to that genus.

In 1903, Schlosser described *Paracamelus gigas* based on an M^1 and an M^2 from the late Pliocene of China. In 1926, Zdansky reviewed this material and referred a skull and jaws and other skeeltal material to the same species. In this review, he pointed out the similarity of the Chinese forms to *Megatylopus gigas* Matthew and Cook (1909) from the Snake Creek fauna. He indicated that these two forms were quite closely related and that the Chinese species might well represent an advance over the North American form. He believed that there was a fundamental difference between the two forms in the tooth reduction, as *Paracamelus gigas* was not supposed to have P^1 and P_1. This belief was proved erroneous by Teilhard de Chardin and Trassaert (1937). Zdansky refrained from placing *Megatylopus* in synonymy with *Paracamelus* as there had been no detailed study made of the limb elements of the American genus.

It is now possible to make a comparison of some of the skeletal elements as material

from the Hemphill of Texas, usually referred to the genus *Megatylopus*, shows a very close affinity to *Paracamelus*. Matthew (MS.) listed this material under the name *Paracamelus arenicola*. A description of his species was never published although Reed and Longnecker (1932) included the name in a faunal list, and it now stands as a *nomen nudum*.

In addition to the skeletal similarities, Teilhard de Chardin and Trassaert (1937) point out that P^1 and P_1 are present in *Paracamelus gigas* Schlosser. These teeth were not preserved in the specimens that were described earlier.

cussed Asiatic forms have insisted that *Paracamelus* is a representative of the line that gave rise to *Camelus*. A review of the material now available seems to indicate that both *Camelus* and *Camelops* were developed from *Paracamelus*, each of the later genera coming from a different line within the ancestral genus.

PARACAMELUS sp.

Locality and specimens.—CIT, 177, Smiths Valley. A right mandible and maxillary, CIT793. V4839, High Ridge. A maxillary fragment, UCMP 38623.

The right mandible and maxillary (CIT

COMPARATIVE MEASUREMENTS OF *PARACAMELUS*

	C.I.T. 177 / 793	After Schlosser	After Teilhard de Chardin and Trassaert				Hemphill		Minnechaduza (UCMP) 29554
			18.909	18.911	12.987	22.192	UCMP 30280	UCMP 30277	
P_3, antero-posteriordiameter	16.0	19.2	18.0	24.0	?25.0	—	15.0	12.8	17.8
P_4, antero-posterior diameter	22.0	26.0	21.0	25.0	—	—	25.5	23.3	24.9
M_1, antero-posterior diameter	32.5	34.7	34.0	33.0	—	—	33.2	31.4	27.5
M_2, antero-posterior diameter	37.0	44.0	37.0	39.0	40.0	—	43.0	36.0	41.7
M_3, antero-posterior diameter	50.0	62.8	54.0	54.0	58.0	—	55.7	—	49.5
P^3, antero-posterior diameter	?28.0	?28.0	—	—	—	31.0	—	—	—
P^4, antero-posterior diameter	?26.0	30.0	—	—	—	29.0	—	—	—
M^1, antero-posterior diameter	33.6	36.0	—	—	—	38.0	—	—	—
M^2, antero-posterior diameter	39.7	?46.0	—	—	—	—	—	—	—
M^3, antero-posterior diameter	43.0	55.0	—	—	—	—	—	—	—
P_3–M_3	158.0	188.0	168.0	171.0	184.0	—	175.0	—	—
P_3–P_4	37.0	43.0	40.0	45.0	?51.0	—	37.0	—	—
M_1–M_3	120.0	?142.0	128.0	124.0	135.0	—	132.0	—	—

In the light of the skeletal similarities and the consideration of the normal variation of the articular facets in the podials of the ungulates, I believe that *Paracamelus* and *Megatylopus* represent the same genus. If this is true, then it follows that due to the identity of the specific names of Schlosser's and Matthew and Cook's species, the latter must be replaced. I propose that *Megatylopus gigas* Matthew and Cook (1909) be known as *Paracamelus brevirostrus*. The trivial name is chosen because the rostrum of the New World species is apparently shorter than that of *P. gigas* Schlosser.

Both Matthew and Cook (1909) and Merriam (1913) have pointed out the similarity between the skulls and dentitions of *Paracamelus* (= *Megatylopus*) and *Camelops*. Nevertheless, the authors who have dis-

793) from Smiths Valley is similar to the forms found in the Hemphill and Minnechaduza faunas. The Smiths Valley specimen differs from the above specimens in having higher crowned P_3 and P_4 and less reduction of the P_3. The P_4 has parallel anterior and posterior vertical margins, which are also seen in *Paracamelus gigas* Schlosser and some North American forms. This character is variable in these New World camels since P_4's with both straight and curved margins occur in individuals from the same faunas. The Nevada specimen is slightly higher crowned than those from the Hemphill, and the P_3 is not as greatly reduced. In this respect it is similar to *P. gigas* Schlosser, but smaller in all dimensions.

It is possible that the Nevada specimen represents a group that gave rise to the large

Asiatic species; and that another group, possibly represented by the Hemphill group, is ancestral to *Camelops*.

A poorly preserved maxillary (UCMP 38623) from High Ridge with the P^3–M^1 is referable to *Paracamelus* and does not differ substantially from the CIT specimen.

CAMELIDAE gen. indet.

Locality and specimens.—V4713, Mickey Wash, site 1. Mandibular fragment, UCMP 38769.

This jaw fragment contains the first two molars and is probably referable to *Paracamelus*, although the M_1 is not as high crowned and the occlusal pattern is quite different from the typical members of the genus. The M_1 has inner and outer pillars between the crescents; the ribs and styles are moderately developed. M_2 has a deep valley between the crescents which nearly divides the tooth into separate halves; the posterior moiety is offset labially to a marked degree which suggests an advanced *Pliauchenia* or *Procamelus*. Isolated foot elements and tooth fragments have been collected in most of the Smiths Valley localities, but most of this material is neither complete nor identifiable.

ANTILOCAPRIDAE gen. indet.

Localities and specimens.—CIT 177, Smiths Valley. Fragments of metapodials and a partial jaw, CIT 796. V4853, Mickey Wash, Site 4. An M^3, UCMP 38774.

The unfortunate diversity of type materials selected for the description of antilocaprids found in the later Tertiary deposits makes the determination of fragmentary specimens a very difficult if not impossible task, especially when the material from a given locality is as scattered and fragmentary as it is in most Nevada faunas.

Several portions of the distal ends of the metapodials (CIT 796) of a large antilocaprid fall within the variation of *Sphenophalos*. A left ramus (CIT 796) containing the M_{1-2} and the roots of P_{2-4} may represent a large *Sphenophalos*, but without associated horn cores it is indeterminate. It should be noted that this specimen also closely resembles a ramus from Mount Eden, California, which Frick (1937, pp. 508–9) referred to (?)*Texoceros edensis* Frick.

The M^3 (UCMP 38774) may belong to either *Sphenophalos* or *Capromeryx* as these forms cannot be distinguished by isolated teeth. This tooth is not unlike an M^3 (UCMP 31525) from Thousand Creek or a series of isolated teeth from Pinole, California which Stirton (1939, p. 387–8) referred to ?*Sphenophalos*. Stirton (1932, p. 51) pointed out that *Sphenophalos* and *Illingoceros* may represent male and female of the same genus rather than representing two closely related genera. The size and apparent crown height of the M^3 indicates at least a Hemphillian age for this specimen.

CONCLUSIONS

I consider the Smiths Valley fauna to be closely related temporally to the nearby Yerington fauna and to the Rattlesnake and Rome faunas of Oregon. The primitive *Dipoides* suggests that this fauna is not as young as the Thousand Creek fauna. The presence of a *Pliohippus* that is close, if not referable, to *P. spectans* (Cope) also indicates an age greater than that of the Thousand Creek fauna but more nearly approaching that of the Rattlesnake fauna. The camel *Paracamelus* is closely related to the known Hemphillian species.

The Smiths Valley fauna is one of the more complete Tertiary faunas from the Great Basin. It gives us a faunal picture that can be equalled only in the Esmeralda, Truckee, and Thousand Creek assemblages.

Although the material is scattered and the stratigraphy is highly complicated by faulting, I believe that the various faunules can be considered as a single unit. The nearby

COMPARATIVE MEASUREMENTS OF *ANTILOCAPRIDAE*

	CIT 796	(?) *T. edensis*
P_2, antero-posterior diameter of alveolus	6.4	4.7
P_3, antero-posterior diameter of alveolus	8.3	6.5
P_4, antero-posterior diameter of alveolus	11.2	9.1
M_1, antero-posterior diameter at alveolar border	13.2	12.8
M_2, antero-posterior diameter at alveolar border	16.2	14.5
P_2–M_2, total length	58.3	51.4

Yerington fauna may be a part of this same assemblage but due to the distance to that area from the Smiths Valley localities and the meager collections that comprise the fauna a definite correlation cannot be made.

LITERATURE CITED

CHARDIN, P. T. DE, & TRASSAERT, M., 1937, The Pliocene Camelidae, Giraffidae, and Cervidae of southeastern Shansi: Paleont. Sinica, (n.s.) (C), no. 1, p. 1–68, 19 figs., 6 pls.

COLBERT, E. H., 1938, Pliocene peccaries from the Pacific Coast region of North America: Publ. Carnegie Inst. Wash., no. 487, p. 241–269, 4 figs., 6 pls.

COPE, E. D., 1887, A saber-toothed tiger from the Loop Fork beds: Am. Naturalist, v. 21, p. 1019–1020.

DAMES, W. B., 1883, Über das Vorkommen von *Hyaenarctos* in dem Pliocan-Abagerungen von Pikermi bei Athen: Sitz. Ber. Ges. naturf. Freuhde, Berlin, v, 8, p. 132–139, pl. XI.

DEPERET, CHARLES, 1895, Resultats des fouilles paleontollogiques dans le Miocene superiour de la colline de Montredon: C. R. Acad. Sci. Paris, v. 121, p. 432–434.

FRICK, CHILDS, 1926, The Hemicyoninae and an American Tertiary bear: Bull. Am. Mus. Nat. Hist., v. 56, p. 1–119, 62 figs.

——, 1937, The horned ruminants of North America: *Ibid.*, v. 69, p. 1–699, 103 figs.

HIBBARD, CLAUDE W., 1944, Two New Mammals from the Middle Pliocene of Seward County, Kansas: Univ. Kans. Sci. Bull., v. 30, p. 107–114, 2 pls.

LYDEKKER, RICHARD, 1878, Indian Tertiary and Post Tertiary Vertebrata: Rec. Geol. Surv. India, v. 10, p. 1–363, 21 figs., 45 pls.

MACDONALD, J. R., 1948, The Pliocene Carnivores of the Black Hawk Ranch fauna: Univ. Calif. Publ., Bull. Dept. Geol. Sci., v. 28, p. 53–80, 15 figs.

——, 1949, A new Clarendonian fauna from Northeastern Nevada: *Ibid.*, v. 28, p. 173–194, 11 figs.

——, 1956, A new Clarendonian fauna from the Truckee formation of western Nevada; Journ. Paleontology, v. 30, p. 186–202, 13 figs.

MATTHEW, W. D., 1929, Critical observations upon Siwalik mammals: Bull. Am. Mus. Nat. Hist., v. 50, p. 59–210, 63 figs.

MATTHEW, W. D., & COOK, H. J., 1909, A Pliocene fauna from Western Nebraska: *Ibid.*, v. 26, p. 361–414, 27 figs.

MECQUENEM, ROLAND DE, 1924–1925, Contribution a l'Etude des fossiles de Maragha: Ann. Paleont. Paris, v. 13, p. 135–160, 4 pls.; v. 14, p. 29–64, 5 pls.

MERRIAM, J. C., 1911, Tertiary mammal beds of Virgin Valley and Thousand Creek in northwestern Nevada: Pt. II. Vertebrate faunas. Univ. Calif. Publ., Bull. Dept. Geol. Sci., v. 6, p. 199–304, 80 figs., 2 pls.

——, 1913, The skull and dentition of a camel from the Pleistocene of Rancho la Brea: *Ibid.*, v. 7, p. 305–323, 11 figs.

MERRIAM, J. C., STOCK, CHESTER, & MOODY, C. L., 1916, An American Pliocene bear: *Ibid.*, v. 10, p. 87–109, 23 figs.

PILGRIM, G. E., 1913, The correlation of the Siwaliks with the mammal horizons of Europe: Rec. Geol. Surv. India, v. 43, p. 264–326, 3 pls.

——, 1931, Catalogue of the Pontian Carnivora of Europe in the Department of Geology: London: Trustees, Brit. Mus. Nat. Hist., p. vi +1–174, 30 figs., 2 pls.

REED, L. C., & LONGNECKER, O. M., 1932, The geology of Hemphill County, Texas: Univ. Texas Bull. no. 3231, p. 1–98, 9 figs., 1 pl.

SCHLOSSER, MAX, 1903, Die fossilen Saugethiere Chinas nehst einer Odontographie der recenten antilopen: Abh. Bayer Akad., v. 22, p. 1–221, 32 figs., 14 pls.

STIRTON, R. A., 1932, An association of horncores and upper molars of the antelope *Sphenophalos nevadanus* from the Lower Pliocene of Nevada: Am. Journ. Sci., (5), v. 24, p. 46–51, 3 figs.

——, 1939, Cenozoic mammal remains from the San Francisco Bay region: Univ. Calif. Publ., Bull. Dept. Geol. Sci., v. 24, p. 339–410, 95 figs.

——, 1940, Phylogeny of North American Equidae; *Ibid.*, v. 25, p. 165–198, 52 figs.

STOCK, CHESTER, 1936, A *Pliomastodon* skull from the Thousand Creek Beds, Northwestern Nevada: Carnegie Inst. Wash. Publ., no. 473, p. 35–39, 1 pl.

WEITHOFER, K. A., 1888, Beitrage zur Kenntnis der Fauna von Pikermi bei Athen: Beitr. Palaeont. Oest.-Uns. Wien, v. 6, p. 225–292, 19 pls.

WILSON, R. W., 1934, A new species of *Dipoides* from the Pliocene of eastern Oregon: Publ. Carnegie Inst. Wash., no. 453, p. 19–28, 1 fig., 1 pl.

——, 1936, A Pliocene rodent fauna from Smith Valley, Nevada: *Ibid.*, no. 473, p. 15–34, 2 pls.

——, 1937, Pliocene rodents of Western North America: *Ibid.*, no. 487, p. 21–73, 2 figs.

ZDANSKY, OTTO, 1924, Jungtertiare Carnivoren Chinas: Paleont. Sinica, v. 2, p. 1–155, 24 figs., 33 pls.

——, 1926, *Paracamelus gigas*, Schlosser: *Ibid.*, (f. 4), v. 2, p. 1–44, 23 figs., 4 pls.

MANUSCRIPT RECEIVED DECEMBER 12, 1958.

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 888–901, 11 TEXT-FIGS., SEPTEMBER, 1959

SIZE AND SHAPE VARIATION IN THE BRACHIOPOD *SCHIZOPHORIA* FROM THE DEVONIAN OF WESTERN AUSTRALIA[1]

J. J. VEEVERS
Bureau of Mineral Resources, Geology and Geophysics, Canberra

ABSTRACT—For brachiopods the only valid basis for reconstructing the size distribution of the original population before burial is a complete sample composed of all the fossil specimens in a given continuous volume of rock. Of the three samples analyzed, one represents a living population in which possibly two age-groups may be recognized, another represents an assemblage which originated by the removal of small valves from a living population by a water current of low competent velocity, while the third, a non-complete sample, gives inconclusive results. A critical comparison with Parkinson (1954) leads to the rejection of the part therein dealing with the comparison of means and variances. Higher degrees of linear correlation of characters in certain size-groups in the samples are probably related to the living position of the shell with respect to the pedicle. The change in shape at a width of approximately 21.5 mm. may be attributed to either environmental or genetic causes.

SIZE DISTRIBUTION

RECENT work in palaeoecology has been directed to determining the kind of population represented by a sample of fossils. The relationship between a population and the sample drawn from it is a crucial one in statistics, and attempts to generalize about populations represented by samples containing comparatively few individuals has led to a great deal of investigation being made into the validity and limitations of samples.

In palaeontology one of the simplest types of this highly complex relationship exists between a population and a fossil sample of one species belonging for the greater part of its life-cycle to the sessile benthos. It is this kind of relationship, as exemplified by fossil brachiopods, that is studied here.

Several authors have already proposed terms to describe the main types of populations found in the fossil state. Thus Boucot (1953), working on brachiopods, gives distinguishing criteria for classifying fossil populations into two kinds which are termed the "life assemblage" and "death assemblage"; these are the fossil (and English) equivalents of the neontological terms biocoenosis and thanatocoenosis. A life assemblage results from the fossilization of the essentially undisturbed remains of a contemporary population of living organisms situated within a particular area. A death assemblage may on the one hand be regarded as a fossilized aggregate of organic remains which were never associated during life, such as the haphazard and miscellaneous mixture of organic remains assembled on most marine beaches. On the other hand, a death assemblage may consist of the fossilized remnants of a biocoenosis from which certain size-groups have been selectively removed or destroyed, so that the size-frequency distribution may differ significantly from that of the original biocoenosis. Common agents leading to the formation of death assemblages would be waves and currents, which by size-sorting might give one or more thanatocoenoses from one biocoenosis.

The chief criterion employed by Boucot is the life-table, which lists information on survival and mortality rates within a living population. The theory for the life-table is summarized by Deevey (1947). Further discussion of this method is given by Kurtén (1954, p. 288–289), who classifies samples as (a) the *census* type representing populations which have been destroyed simultaneously, and (b) the type recording normal mortality in a population.

Other authors, including Kermack (1954), refrain from inventing new words or phrases because they consider that every population

[1] Published by permission of the Secretary, Department of National Development.

is unique and cannot be included with other populations under the same name.

Attempts at condensing the description of the type of population into a single word are generally, in my opinion, impracticable. That there are a few general types of population is acceptable only in the very broadest sense. The greater accuracy now required in palaeoecological studies demands that these terms be replaced, not by newly coined terms which would tend to cause serious verbal inflation, but instead by simple qualifying phrases which uniquely describe each population. General terms such as "community" and "assemblage" are useful in palaeoecology in the same way as the term "form" is useful in systematics. These words function best as informal expressions in contexts where strictly defined terms are not required.

In general, the size distribution of a population of brachiopods living together in a closely associated community may be modified in one or more of three stages during the time interval between the death of members of the population and the arrival in the laboratory of the fossil sample representing this population:

(1) Before burial. The disarticulation of some or all shells may or may not be accompanied by the scattering of individuals to form one or more assemblages with different size distribution from that of the original living population.

(2) During fossilization and entombment within rock strata. Certain individuals may be preferentially preserved; e.g., if recrystallization takes place, smaller specimens are more likely to become obliterated than larger ones; where the fossils have undergone replacement, as in silicification, the lower limit to the size of specimens ultimately preserved will be controlled by the delicacy and degree of fineness of the process of replacement.

(3) During sampling. This kind of modification depends closely on the nature of preservation and the technique used in sampling:

(i) Where brachiopods have been replaced (say by silica in a limestone matrix), and individuals of all sizes have been equally well preserved, the fossil population released by dissolving the matrix in acid will not have been modified, except in a chemical sense; fossils embedded in a soft clay may be freed by removal of the clay matrix, and fossils in shale may be exposed, if not freed, by careful splitting of the shale along the bedding planes. Boucot used this technique for exposing brachiopods in a Devonian shale (Boucot, 1953, p. 36–40). In these and similar ways a close approximation to the size distribution of the population of shells existing immediately prior to burial will be obtained. For the sample collected in this way the term "complete sample" is proposed. A complete sample is composed of all the fossil specimens is a given continuous volume of rock. If all individuals have been preserved, a complete sample of sufficient size will be a faithful reflection of the population existing immediately prior to burial.

(ii) Many fossils are found embedded in a tough matrix from which only a few specimens may be released in a satisfactory condition. Fossils may also be found in a free state (that is, free of externally adhering sediment) on the surface as the result of weathering; if so, it will generally be impossible or impracticable to collect a complete sample. This is the conclusion reached by Burma (1947, p. 727):

> "Obviously the best sample would be one in which the entire range of variation in the population is represented, and in the same proportions. . . . In practice, a sample is usually taken by going to an outcrop and picking up whatever specimens are available. Under these circumstances this is the best method of sampling *for the sample will then be as nearly random as possible*" (my italics).

It is important to realize the significance of the italicized clause above, viz., that the sample will be as nearly as possible *a random sample of all the fossils available at the outcrop*, but not necessarily a random sample of all the fossils embedded in the rock. In proportion to the degree of difference between the population of fossils available at the outcrop and the population of fossils embedded in the rock, Burma's type of sample will be biassed from the latter, and a significant bias will invalidate the use of such a sample in size distribution studies. For such studies the complete sample will be the only valid basis.

Some of the points mentioned above are illustrated by a size distribution study

based on three samples of the brachiopod genus *Schizophoria*.

SAMPLING TECHNIQUE

The samples are from the collections of the Bureau of Mineral Resources, Geology and Geophysics, Canberra, and for the purposes of this paper are designated A, B and C. (B.M.R. registration numbers are, sample A: F18312; sample B: F18308, F18309, F18311; sample C: F18334–F18337 incl.)

Samples A and B are *Schizophoria stainbrooki* Veevers, 1959, and sample C belongs to *S. apiculata* Veevers, 1959. Sample A was collected 70 ft. and sample B 100 ft. stratigraphically above the base of the type section of the Sadler Formation of Upper Devonian age near Sadler Ridge, Kimberley Division, Western Australia. The outcrops from which the samples were collected, the technique of sampling, and the laboratory development of the fossils, were essentially the same for both samples. The outcrops strike along the side of a gently sloping hillside; the rock-type is calcarenite, crammed with the silicified remains of *Schizophoria stainbrooki*, stromatoporoids and corals. Each sample was chosen from a part of the outcrop which contained *Schizophoria stainbrooki* only; a plate of calcarenite 10 cm. square was broken off the outcrop along the bedding so that the sample includes fossils from a bed 4 cm. thick. In the laboratory the silicified material was dissolved out of its calcareous matrix by cold 10% acetic acid. No specimens above a certain minimum size (1.5 mm.) within the rock seem to have escaped the process of silicification. Small specimens, like the larger ones, are entirely replaced by silica.

Sample C consists of calcareous shells with no externally adhering sediment (the term "shell" is applied to specimens in which the valves are articulated). The sample was collected from an isolated surface outcrop in the Fairfield Beds of Upper Devonian age, Fossil Downs, Kimberley Division. The sample consisted solely of the loose shells of *Schizophoria apiculata*. All the visible specimens within a surface area of 15 sq. metres were picked up.

SAMPLES A AND B

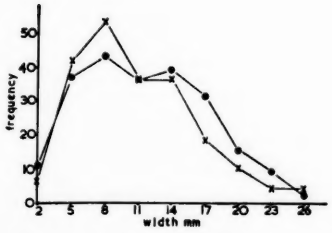
Composition.—The composition is as follows:

Sample A	Sample B
1 shell	2 shells
228 free dorsal valves	181 free dorsal valves
282 free ventral valves	151 free ventral valves

Each random sample may have been drawn from a population composed either of an equal or an unequal number of ventral and dorsal valves. The Normal Probability Table shows that the probability that A was drawn from a population with equal numbers of valves is $P=0.015$; for B, $P=0.089$. It is valid to take a significance level of $P<0.05$; so that the value for A is significant whereas that for B is not. In other words, the difference in numbers in sample B may be attributed to random sampling, whereas that of A may not, and sample A may reasonably be assumed to have been drawn from a population with unequal numbers of valves immediately before burial.

Age characters.—Boucot (1953, figs. 1–5, p. 28, 248) implicitly correlates size and age without qualifications. This correlation, however, is valid only where the ranges of size variation for each age-group do not overlap. The assumption of insignificant variation within age-groups in brachiopods is supported by the studies of Percival (1944) on the living brachiopod *Terebratella inconspicua* (G. B. Sowerby). If this assumption is acceptable, a size-frequency distribution may be considered an analogue of the mortality distribution. Width is the best single character in brachipods for measuring size; it is readily measured, and moreover, the widths of the component valves of a shell are the same. Where the shells are disarticulated the comparison of the width-frequency distributions of opposite valves indicates those size-groups which react differently to agents tending to break up the size distribution of the life assemblage. Parkinson (1952, p. 211, 212) finds in *Dielasma hastata* (J. de C. Sowerby) from the Lower Carboniferous reef limestone of Treak Cliff, Derbyshire, that while width varies uniformly, length and thickness vary nonuniformly with shell volume.

On the assumption that each growth-line in a brachiopod is formed during an equal period of time, it might be suggested that the number of growth-lines of a valve is a



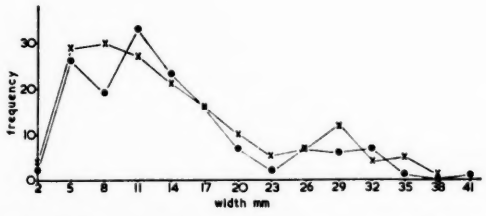
TEXT-FIG. *1*—Width-frequency polygons of 208 dorsal valves (crosses) and 222 ventral valves (dots) of sample A (*Schizophoria stainbrooki*)

close correlate of age. Unfortunately this character is found to be unsuitable for measurement in the species studied, since the growth-lines are irregular in shape, spacing and distinctness.

Mortality curves.—The numbers of specimens whose width cannot be measured are 20 dorsal and 80 ventral valves in sample A, 10 dorsal and 1 ventral valve in sample B. In sample B the rejection of this small number of valves will not appreciably distort the size distribution, but in sample A the larger number will lead to a size distribution less closely representative of the original distribution.

Text-figures 1 and 2 are the width frequency polygons (analogues of mortality curves) of dorsal and ventral values of samples A and B respectively; in both cases a grouping unit of 3 mm. is found most satisfactory for the available numbers of specimens. The following features are to be noted:

(a) The polygons are strongly skewed to the right.
(b) The distributions for ventral and dorsal valves are similar in both samples.



TEXT-FIG. *2*—Width-frequency polygons of 171 dorsal valves (crosses) and 151 ventral valves (dots) of sample B (*Schizophoria stainbrooki*).

(c) The first modes are found in the width interval 5 mm. to 11 mm. For higher width values, the frequencies decrease linearly to values of 23 mm. to 26 mm., at which values specimens of sample A have their maximum width.
(d) In sample B a second mode is reached in the width interval 23 mm. to 35 mm. For higher width values, the frequency falls off asymptotically to the maximum widths of 38 mm. for dorsal and 41 mm. for ventral valves.

Text-figure 2 is markedly similar to Percival's width-frequency distribution of a census-type sample collected from a living population of *Terebratella inconspicua* (Percival, 1944, text-fig. 1). Percival claims to find four modes in this distribution, suggesting that each mode represents different age-groups (sets) ranging in age from one to four years. It is possible, by analogy with Percival's work, that the second mode of text-fig. 2 represents the second-year age-group, while the first mode represents the first-year age-group. This would imply an increase in width in *Schizophoria stainbrooki* of the order of 12 mm. to 20 mm. in the second year.

In the width-frequency polygon of ventral valves of sample B (text-fig. 2) the low point within the first mode between width values 5 mm. and 11 mm. may indicate that a few ventral valves with width value between 6.5 mm. and 9.5 mm. were either destroyed or removed from the assemblage before burial.

Conclusions.—The comparison of samples A and B in the following table shows the cardinal differences.

Sample B, owing to (a) the unequal numbers of dorsal and ventral valves being attributable to random sampling, and (b) the similarity in width distribution between this sample and Percival's census-type sample of a living population of *Terebratella inconspicua*, may be taken as a census-type sample representing a living population in which possibly two age-groups are present. The factor or factors responsible for disarticulating all but two shells of sample B did not remove the freed valves.

Since the individuals of samples A and B are morphologically identical over the width range 2 mm. to 26 mm., both samples are

Sample A	Sample B
1. Difference in numbers of opposite valves represents unequal numbers of opposite valves in the parent population existing before burial.	1. Unequal numbers of opposite valves are within the limits expected from the random sampling of a population with an equal number of dorsal and ventral valves.
2. Width range 2 mm. to 26 mm., width-frequency distribution right-skewed, not asymptotic for high width values.	2. Width range 2 mm. to 41 mm., width-frequency distribution right-skewed, asymptotic in width interval 29 mm. to 41 mm.

probably representative of the same chronological subspecies; and, since the part of the geological section from which the samples were collected is uniform, it is likely that both original living populations were subject to similar though not necessarily identical environmental conditions: therefore the biocoenosis from which sample A originated probably had a width range similar to that of sample B, that is, with maximum width of specimens about 40 mm.

By the application of one of the tentative conclusions reached by Menard & Boucot (1951), viz., that "The velocity required to initiate the motion of a [terebratuloid] shell depends on the sphericity of the shell as well as on the size and weight," it is seen that sample A represents those individuals of the living population removable by a water current of low competent velocity since (a) only shells of width less than 26 mm. are represented, and (b) ventral valves (low sphericity) are commoner than dorsal valves (convex, high sphericity).

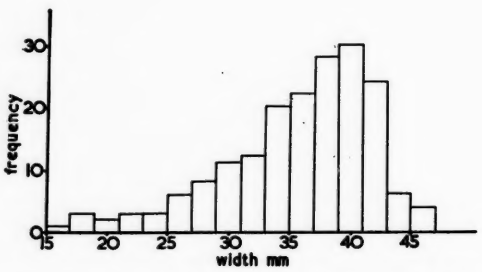
From these premises, one possible origin for the population of fossils represented by sample A is that, from a living population with size range and size distribution similar to that of sample B, the group of free valves of small size and low sphericity is removed by a current with a low competent velocity. This group of valves is deposited after a reduction in the velocity of the carrying current, and subsequent burial preserves the peculiar size range and size distribution found in sample A. Alternatively the larger valves might have been removed or destroyed by predators, for example, to give the same size distribution.

SAMPLE C

In contrast to the analysis of the two complete samples, A and B, it might be instructive to attempt an analysis of the noncomplete sample C, collected from a surface outcrop of loose free specimens. The sample consists of 183 unbroken shells of *Schizophoria apiculata* preserved in partly recrystallized calcite; there were no disarticulated valves at the outcrop.

The width-frequency distribution (text-fig. 3) is a very regular left skew; the mode is at 40 mm., and the minimum shell width is 16.4 mm. If none of the specimens has been removed by surface weathering, thus preserving the width distribution of the population of fossils embedded in the weathered layer of rock, the sample would represent an assemblage derived from a living population by the removal of smaller size-groups before burial. The smaller size-groups, however, might have been removed from the living population not before burial but after the fossil population had been exposed at the surface, where erosional agents could equally well have effected the breaking up of the original size distribution.

The question of the date of removal of the smaller specimens (whether before burial or after exposure of the fossils at the surface) can only be answered by the evidence available from a complete sample. The inter-



TEXT-FIG. 3—Width-frequency histogram of the 183 shells of sample C (*Schizophoria apiculata*).

pretation of a size distribution analysis which is not based on a complete sample is thus seen to be equivocal and consequently of little worth.

SHAPE VARIATION

INTRODUCTION

The valid interpretation of variation analyses requires full recognition by the palaeontologist of the limitations inherent in fossil material.

Richards & Kavanagh (1945, p. 203–210) classify the data from studies on relative growth into five types, three of which require direct time measurements. The two types of data independent of time measurement are thereby available from fossil material. These are: "Type B" of Richards and Kavanagh, derived from a sample composed of individuals of the same age; one set of measurements is made on each individual. These measurements thus show the variation is size of a group of individuals which have reached a certain stage of development.

An example of the application of data of type B is provided by Coleman (1951), who uses samples of the brachiopod genus *Atrypa* from the Devonian of Western Australia. By assuming that the closely crowded growth-lines found near the anterior margin of his specimens marked the outline of the mature shell, Coleman measures the size variation in individuals at the same stage of the life-cycle.

The other type of data, "type D" of Richards and Kavanagh, is derived from measurements made on a group of organisms without regard to difference between the developmental stages of the individuals. "Variation due to time and that due to individual differences are so intermingled that it is difficult or impossible to separate them and to interpret the biological meaning of the constants obtained from fitting the allometry equation. The strict curve relation between x and y does not exist; the correlation kind usually does" (p. 207, 208).

Type D is by far the commoner type met with in palaeontology, since most samples include several developmental stages indistinguishable from one another.

Analysis is often carried out by use of the allometry equation,

$$y = bx^k,$$

where y and x are metrical characters, b and k are constants. In the growth of many organs k remains constant. In the special case where k is constant, equal to unity, the relationship is called isometric. Where k is not constant it must be judged whether the curve should be considered a straight line or a combination of two or more straight lines with breaks.

MEASUREMENTS AND ERRORS

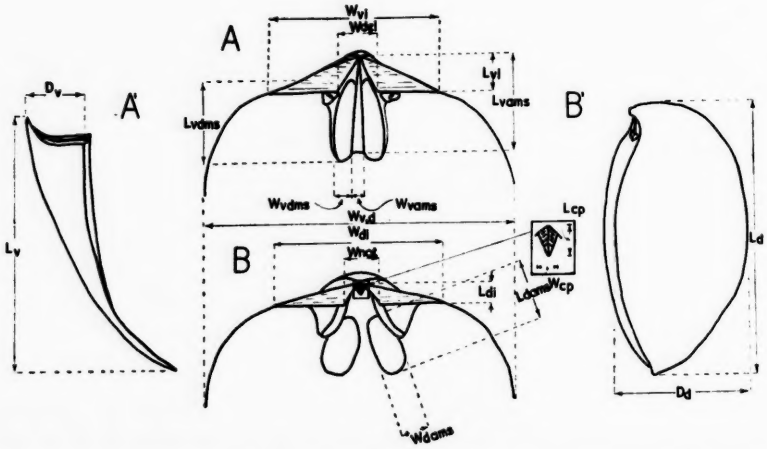
In sample B, 95 ventral valves and 127 dorsal valves were measurable for most of the following characters, illustrated in text-fig. 4.

Ventral valves	
1. Length of valve	Lv
2. Width of valve	Wv
3. Depth of valve	Dv
4. Length of interarea	Lvi
5. Width of interarea	Wvi
6. Width of delthyrium	Wdel
7. Length of adductor muscle scar	Lvams
8. Width of adductor muscle scar	Wvams
9. Length of diductor muscle scar	Lvdms
10. Width of diductor muscle scar	Wvdms

Dorsal valves	
1. Length of valve	Ld
2. Width of valve	Wd
3. Depth of valve	Dd
4. Length of interarea	Ldi
5. Width of interarea	Wdi
6. Width of notothyrium	Wnot
7. Length of adductor muscle scar	Ldams
8. Width of adductor muscle scar	Wdams
9. Length of cardinal process	Lcp
10. Width of cardinal process	Wcp

In sample A measurements of characters 1 to 5 inclusive were possible for 218 ventral valves and 209 dorsal valves; only well-preserved valves, in which these characters were clearly measurable, were used.

The particular value of these samples as bases for shape analysis arises from (a) their being composed (except for three shells) of free valves, thereby allowing the measurement of simple valve characters rather than the more composite characters measured from shells, and (b) their morphological identity over the width range 2 mm. to 26 mm., implying genetic identity. The ab-



TEXT-FIG. 4—Characters measured in *Schizophoria stainbrooki* n. sp. A, posterior half of ventral valve A′, lateral view; B, posterior half of dorsal valve; B′, lateral view. The letters refer to the metrical characters listed on p. 893.

sence of shells less than 16 mm. wide in C makes it unsuitable for shape analysis.

Since the characters are clearly defined on the valve, measurement was simple and rapid, and reproducible.

The main statistical measure affected by such errors is the correlation coefficient. In an attempt to compensate for errors a probability level of $P < 0.01$ has been chosen as significant for this coefficient.

Samples A and B give date of type D of Richards and Kavanagh, and tables of the values of the characters may be considered as correlation tables. Analysis was effected by comparing two characters at a time; their scatter was plotted on log scales; reduced major axes (Kermack & Haldane, 1950) and correlation coefficients were computed where these might bring out relationships not otherwise apparent. Since the pairs of characters presented give linear scatters on arithmetical scales, the use of the correlation coefficient of arithmetical characters (r′) is valid.

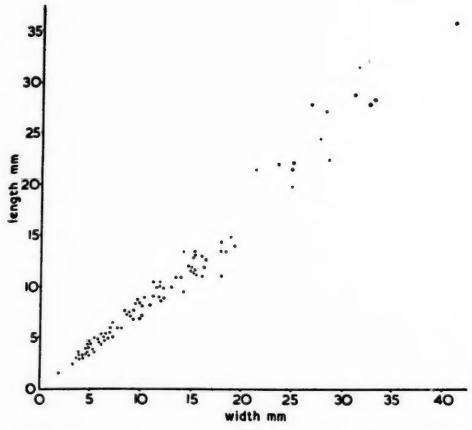
ANALYSIS OF SAMPLE B

Length, width, depth.—The scatter of Lv and Wv on arithmetical scales is given in text-fig. 5, on log scales in text-fig. 6 and the scatter of Ld and Wd on log scales in text-fig. 7. A common feature of these scatters is the two-fold division, into (a) the scatter over the width interval 3 mm. to 21.5 mm., and (b) the scatter over the width interval 21.5 mm. to 40 mm. The sample was divided into two parts, corresponding to the two width intervals. Scatters of W and D, L and D, on log scales (not shown) indicate a division again at W = 21.5 mm.

Coefficients of total correlation for pairs of arithmetical characters were determined separately for the two width intervals (table 1). All correlations in this paper are positive in sign. These values have a level of significance, $P < 0.01$. The following remarks may be made: (a) r′ in each case is greater for the pairs of characters for the width interval W < 21.5 mm., than for r′ of the same characters over the interval W > 21.5

TABLE 1.—SAMPLE B—COEFFICIENTS OF TOTAL CORRELATION

Ventral valves		*r*′(L, W)	*r*′(W, D)	*r*′(L, D)
n = 81	width < 21.5 mm.	0.9330	0.7540	0.7961
n = 14	width > 21.5 mm.	0.9249	0.6754	0.7832
Dorsal valves		r′(L, W)	r′(W, D)	r′(L, D)
n = 105	width < 21.5 mm.	0.9810	0.9372	0.9444
n = 22	width > 21.5 mm.	0.8506	0.6105	0.8297



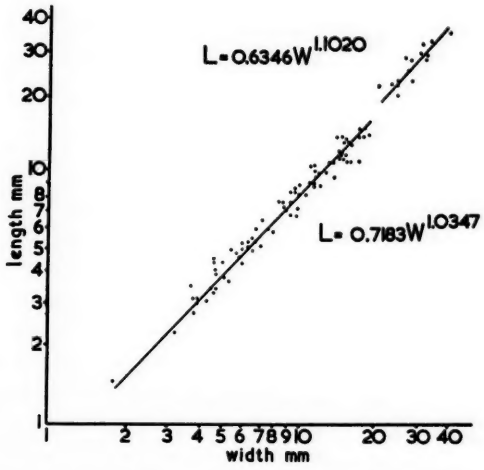
TEXT-FIG. 5—Scatter diagram on arithmetical scales of length plotted against width for 95 ventral valves of sample B (*Schizophoria stainbrooki*).

mm.; (b) the results of tests of significance of differences between r′ of the same characters for the two width intervals (using the "z-transformation" of Fisher) are:

Pairs of characters	Difference between value of r′ for W<21.5 mm., and of r′ for W>21.5 mm.
Lv and Wv	not significant (N.S.)
Ld and Wd	significant (P<0.001)
Wv and Dv	N.S.
Wd and Dd	S. (P<0.001)
Lv and Dv	N.S.
Ld and Dd	probably significant (P<0.02)

In ventral valves total correlations are of similar degree for length and width, width and depth, and length and depth over the entire width range; in dorsal valves, however, correlation between these pairs of characters is significantly less in the interval W>21.5 mm., than in the interval W< 21.5 mm.

The comparison of correlation coefficients for corresponding pairs of characters in opposite valves gives the following results: (a) in the interval W<21.5 mm., r′ of a pair of ventral valve characters differs from r′ of the corresponding pair of dorsal valve characters to a highly significant degree (P<0.001); for example, for W<21.5 mm., the difference between r′ (Lv, Wv) (=0.933) and r′ (Ld, Wd) (=0.980) is highly significant; (b) in valves with W>21.5 mm., corresponding differences are not significant.

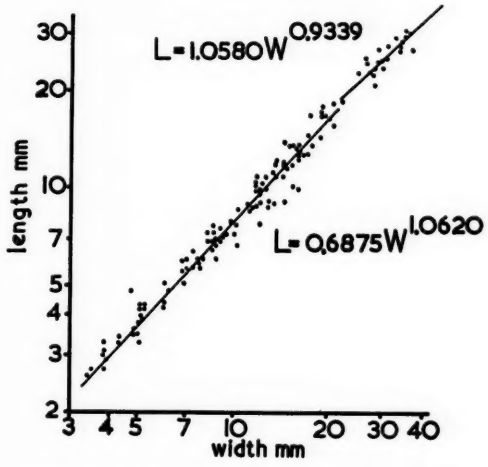


TEXT-FIG. 6—Scatter diagram and reduced major axes on log scales of length plotted against width for 95 ventral valves of sample B (*Schizophoria stainbrooki*).

The correlations may be summarized as follows:

	W<21.5 mm.		W>21.5 mm.
Dorsal valves	r′	>	r′
Ventral valves	r′	≃	r′

These relationships imply that linear association between arithmetical L, W, and D is of a similar order of magnitude for



TEXT-FIG. 7—Scatter diagram and reduced major axes on log scales of length plotted against width for 127 dorsal valves of sample B (*Schizophoria stainbrooki*).

ventral and dorsal valves over the entire width range, except in dorsal valves with W <21.5 mm. in which these characters have a significantly higher association. This result agrees with general observations, summarized by Cooper (1944, p. 282):

> "As the brachiopod is attached by the pedicle or by the ventral valve itself, this valve is more modified than the dorsal, which serves as a lid. This is the conservative valve and is never used for attachment."

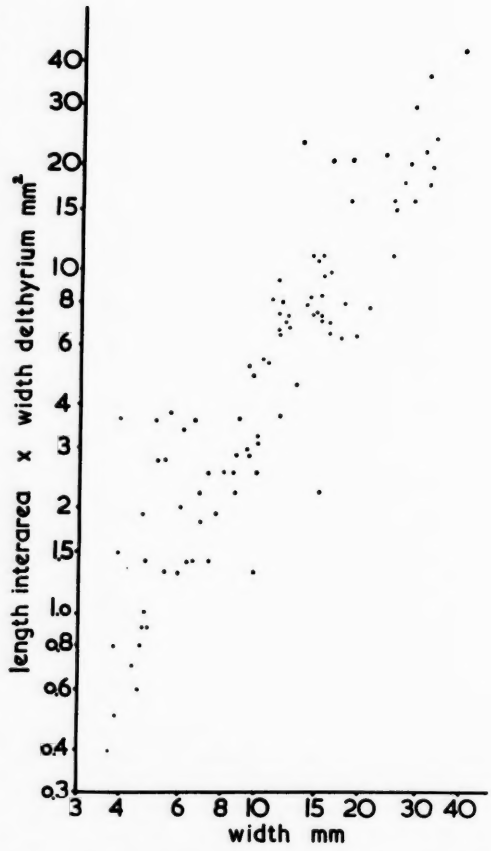
The lower correlations in dorsal valves with W >21.5 mm., showing a diminution in the degree of associated variation, could result from changes in pedicle position taking place in maturity.

Hinge characters.—The characters concerned are Nos. 4,5 and 6 of p. 893. The regular triangular outline of the ventral interarea, deltyrium, dorsal interarea, and notothyrium, allows simple calculation of areal characters: e.g.,

Lvi×Wvi∝ area of interarea
Lvi×Wdel∝ area of delthyrium
Ldi×Wnot∝ area of notothyrium

For simplicity the area of the interarea is taken as bounded by the beak-ridges and the hinge-line, thus including the area of the delthyrium in ventral valves, and the area of the notothyrium in dorsal valves.

The scatters of Lvi and Wvi, and Ldi and Wdi, on log scales are linear in shape. Correlation coefficients for (Lvi, Wvi) and (Ldi, Wdi) were computed separately for the two width intervals:

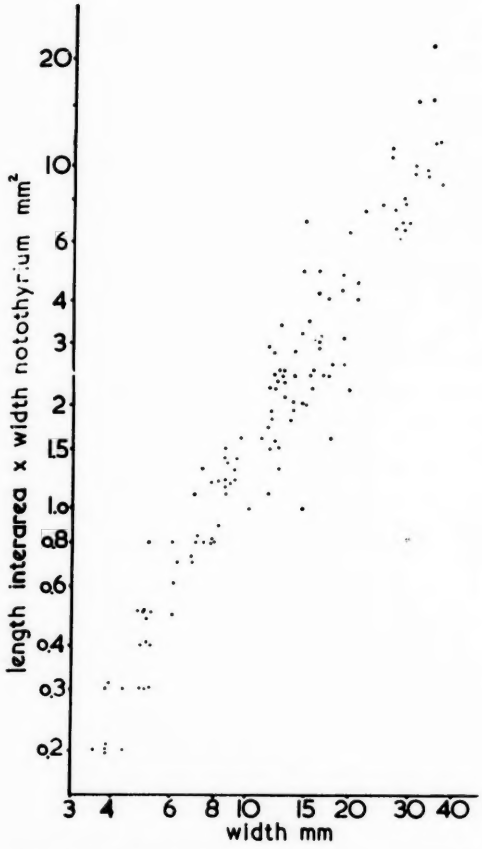


TEXT-FIG. 8—Scatter diagrams on log scales of a factor of the area of the delthyrium plotted against valve width for 92 ventral valves of sample B (*Schizophoria stainbrooki*).

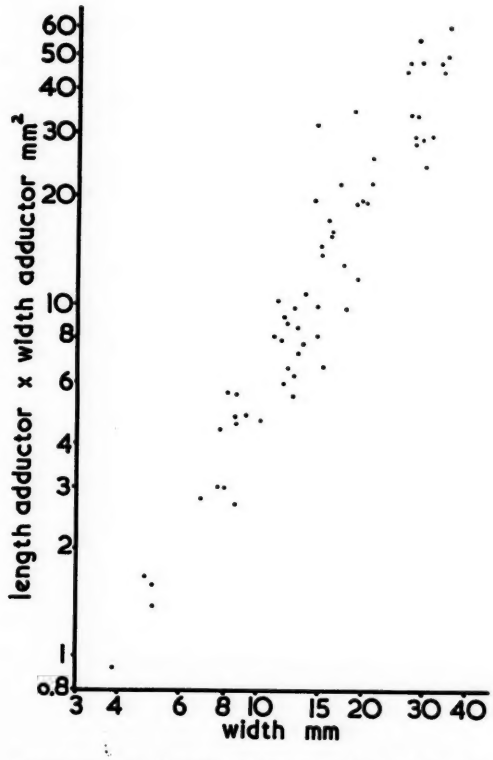
r′(Ldi, Wdi)	W <21.5 mm.	0.8975	n =105	significant
	W >21.5 mm.	0.3579	n = 22	not significant
r′(Lvi, Wvi)	W <21.5 mm.	0.9680	n = 81	significant
	W >21.5 mm.	0.2799	n =14	not significant

In the interval W <21.5 mm., the values of r′ are significant for ventral and dorsal valves and moreover the difference between the values of r′ for opposite valves (0.9680–0.8975) is highly significant (P <0.001), implying that linear association between those characters is higher in ventral than in dorsal valves.

The moderate degree of linear relationship on log scales between (Lvi×Wdel) and Wv, (Ldi×Wnot) and Wd, is illustrated in text-figs. 8 and 9 respectively. The spread normal to the gradient of the scatters implies that linear association of these analogous characters is apparently higher in dorsal than in ventral valves. This result supports the



TEXT-FIG. *9*—Scatter diagram on log scales of a factor of the area of the notothyrium plotted against valve width for 127 dorsal valves of sample B (*Schizophoria stainbrooki*).



TEXT-FIG. *10*—Scatter diagram on log scales of a factor of the area of the adductor muscle-scar plotted against valve width for 64 dorsal valves of sample B (*Schizophoria stainbrooki*).

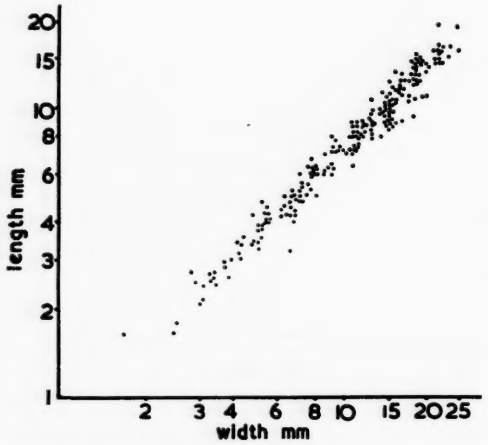
idea that the delthyrium, being in intimate connection with the pedicle, would be subject to greater, probably unassociated, incidental variation than the notothyrium.

Muscle scars.—The fairly regular elliptical outlines of the ventral diductor and the dorsal adductor scars, and the triangular outlines of the ventral adductor and dorsal diductor (cardinal process) scars, allow approximate measurements of these areal characters to be derived from the products of the relevant measured characters (characters 7–10 inclusive, p. 893). From the scatters on log scales of the areas of the adductor and diductor scars plotted against valve width, a moderately high degree of linear association may be inferred. (Of the four scatters, only one, text-fig. 10, is shown).

ANALYSIS OF SAMPLE A

Length, width, depth.—The arithmetical scatter of length and width (not shown) is linear, without an apparent break into two parts of different gradient (*cf.* sample B). The continuous linear relationship is expressed more clearly on log scales (text-fig. 11). Scatters of width and depth, length and depth (neither shown), give no indication of a break.

Hinge characters.—The difference between the correlation coefficients for arithmetical values of Lvi, Wvi, ($r' = 0.80$) and Ldi, Wdi ($r' = 0.97$) is highly significant ($P < 0.001$); this contrasts with the corresponding result for sample B, in which the ventral hinge characters are significantly more highly correlated than the dorsal characters. How-



TEXT-FIG. *11*—Scatter diagram on log scales of length plotted against width for 218 ventral valves of sample A (*Schizophoria stainbrooki*).

ever, this is not the only difference observed in the hinge structures of samples A and B. In sample B only, there occurs irregularly an apical plate (pedicle collar) which fills the posterior part of the delthyrium. Of the measurable 95 ventral valves of sample B, only 31 (width range 3.2 mm. to 32.1 mm.) have an apical plate; good preservation permits the inference that the irregularity of apical plate occurrence is not dependent on preservation. Contrary to Schuchert & Cooper (1932, p. 6,22,23), Williams (1956) has shown that the apical plate (or pedicle collar) did not serve as a pedicle attachment, but instead always lay on the outer or ventral side of the part of the pedicle posterior to the pedicular capsule, which itself was attached to the shell. If the secretion of the apical plate, leading to changes in the attitude of the pedicle with respect to the shell, were controlled by apparently random environmental causes, as appears to have been so in sample B, it is possible that this irregular occurrence is responsible for the reduced linear correlation of length and width of the dorsal interarea compared with that of the corresponding characters of the ventral interarea. An iregularity in the attitude of the pedicle might be expected to affect rather the ventral than the dorsal valve, but if the change in attitude of the shell were from roughly a horizontal to an oblique position, with the ventral valve uppermost, the dorsal umbo and interarea would be subjected to irregular stresses from either the pedicle or the substratum. The reduced linear correlation between the length and width of the dorsal interarea is, therefore, likely to be an expression of the adaptation of the shell to these stresses. By contrast, in sample A where the apical plate is not present, where the pedicle position was apparently uniform throughout the part of the life-cycle represented by the sample, and the dorsal valve subjected to uniform stresses, linear correlation is higher for dorsal hinge characters than for the corresponding ventral characters.

COMPARISON WITH PARKINSON (1954)

Parkinson's analysis is based on several samples of shells of *Schizophoria resupinata* (Martin) from the Lower Carboniferous limestones of northern England. Complete samples were not intentionally collected; however, one sample (Treak Cliff) may be complete. The main sample of 1700 individuals was collected over a few hundred feet of section within a topographical range of nearly twenty miles.

By a comparison of means and variances of the ratios length: width, thickness: length, and length of brachial valve: length of pedicle valve, Parkinson claims that there are highly significant statistical differences in shell-shape between populations of two stratigraphical zones and less significant statistical differences between populations within the one zone. Furthermore these differences are considered to be expressions of phylogenetic change.

In a later part, the characters used in the ratios mentioned above are also shown to be allometrically related. An important property of the ratio of allometrically related characters is that the value of the ratio depends upon the age (or size) of the organism. Therefore, it must follow that Parkinson is not justified in claiming to find biological differences within his collection on the basis of means and variances, unless he can prove that the age distribution of the samples is the same. Unfortunately the paper contains abundant evidence to disprove age uniformity in the samples. On such a basic contradiction this part of the analysis must be rejected.

The greater part of Parkinson's paper is devoted to a study of shape features, for which his material affordes suitable valid data. Kermack (1954, p. 392) may be quoted aptly at this point; in discussing the assumption often made in palaeontology that the age distribution of a sample is the same as that of the living population, Kermack states:

> "In fact, however, it is possible to avoid making any such assumptions about the age distribution of the sample if 'size' parameters, such as means and medians, are abandoned for the purpose of comparison, and 'shape' parameters are used instead. The age distribution of the sample will have little effect, if any, upon the values of the estimates of 'pure' shape parameters. This makes the use of the latter of particular value in quantitative palaeontology where the age distribution of the sample is dependent upon that of the original living population in a very complex and indirect way. . . ."

Parkinson's main conclusion is that for the characters length, width and thickness, considered two at a time, there is an apparent change taking place at a width of about 20 mm. in the value of k, the exponent of the allometry equation. For specimens of the Craven Reef Belt sample, and for characters shell length and width, the estimate of k for the width interval 5 mm. to 20 mm. is 1.032, whereas for the interval W > 20 mm., the estimate is 1.010. A shortcoming of the analysis is that tests of statistical significance have not been applied to the difference between these estimates. It is possible, though highly improbable in view of the large numbers of specimens involved, that these estimates are not significantly different, and moreover, that one or both of them might not differ significantly from unity. Without the application of significance tests it is not strictly valid to claim a real change in k, since such values might have arisen from random sampling of populations with identical k.

Changes in k for width and thickness and also length and thickness are of greater degree and consequently the probability that these differences arise from random sampling is correspondingly less.

With the hope of achieving a closer comparison between Parkinson's work and the present analysis, reduced major axes (Kermack & Haldane, 1950) were fitted to the scatters of length and width in dorsal and in ventral valves from sample B. The breaks in the scatters illustrated in figs. 5,6,7 are expressed numerically by the two sets of values of k:

	W < 21.5 mm.	W > 21.5 mm.
Ventral valves	1.0347	1.1020
Dorsal valves	1.0620	0.9339

A test shows that the differences between the estimates of k for the two width intervals are highly significant. By a similar test, however, it is shown that the differences between the estimates of k and unity are probably significant (P = 0.025) for three of the estimates, only the fourth (with k = 1.1020) having a highly significant difference from unity. Thus in one case only, for the characters length and width, is allometry clearly indicated.

An interesting feature of the equations of the reduced major axes (in apparent contrast to Parkinson's results) is that whereas the estimated value of k for width >21.5 mm. decreases in dorsal valves, the corresponding index *increases* for ventral valves, implying a fundamental difference in shape between valves of the two width intervals.

In *Schizophoria stainbrooki* the measurement of shell length is composite, equal in some specimens to Lv, in some to Ld, and in others measured equally by Lv and Ld. It follows that in this species, the use of shell length as a character for analysis will yield composite results. That the specimens of *S. resupinata* studied by Parkinson also have a similarly composite shell length is evident from diagrams E and F of fig. 2 (Parkinson, 1954, p. 368); fig. 2E illustrates a shell with the pedicle valve longer than the brachial valve, and fig. 2F one with the brachial longer than the pedicle valve.

Parkinson's reduced major axes for such composite shell characters as length and thickness, each plotted against shell width, may be considered analogous to the algebraic sums of the constituent valve characters (valve length, valve depth) each plotted against valve (shell) width. Although Parkinson found a decrease in the estimate of k for the characters of shells with W > 20 mm.

(using shell length, thickness, and width), this does not necessarily imply that the estimate of k for corresponding ventral valve characters (Lv, Dv and Wv) also decreases in this width interval, a result which would contrast with that found in the present paper. A small increase in k for these ventral valve characters would be masked by a large decrease in k for corresponding dorsal valve characters, so that the compounded value of k for shell characters would show a decrease.

The information from Parkinson's paper and the present study suggests that either a difference in environmental conditions or a genetic cause might be invoked to account for the shape variation denoted by the different values of k.

In support of an environmental origin it may be noted that not all samples show a change in the estimate of k in the approximate width interval 20 mm. to 25 mm. (e.g., Parkinson's *Dielasma* Bed sample and sample A of the present study). The constant shape of specimens in these samples therefore may be attributed either to a constant environment, or if the environment changed, to an adaptation of the specimens by means other than shape.

On the other hand, the implications arising from the examination of valves within the width interval 20 mm. to 25 mm. lend support to a postulated genetic origin for the shape chage. Valves within this width interval (excluding those in the *Dielasma* Bed sample and sample A) share two important characteristics which distinguish them from valves outside this interval: (a) they change shape, and (b) they probably represent the junior part of the second age-group (see p. 892). If these two characteristics are related, the cause must be genetic—the shape change occurring in the ontogeny at the beginning of the second age-group. In the *Dielasma* Bed sample and sample A, a width greater than 25 mm. might have been attained by individuals which lived in environments particularly suitable for rapid growth before they entered the second age-group, so that a shape change would occur in specimens greater than 25 mm. in width. Unfortunately shape constancy or inconstancy in these specimens cannot be measured because not enough specimens with width >25 mm. occur in the samples.

SUMMARY AND CONCLUSION

1. Modifications in the size distribution of a living community of brachiopods are traced from the time before the burial of its constituent individuals up to and including the time when the fossil sample is collected.

2. Two complete samples (A and B) and one probably non-complete sample (C) of *Schizophoria* were collected. Of the former, one (B) represents a living population in which possibly two age-groups may be recognized, the other (A) may represent an assemblage which originated by the removal of valves from a living population by a current of low competent velocity and their deposition and burial elsewhere. The conclusions arrived at for the non-complete sample are shown to be equivocal.

3. The scatters of length and width, width and depth, length and depth show a division at an approximate width value of 21.5 mm. in sample B. Linear association is significantly higher in dorsal valves with width <21.5 mm., than for the same measure of association in dorsal valves with width >21.5 mm. and in all ventral valves. No break in the scatters of these characters is indicated in sample A.

4. Whereas in sample B linear association between the length and width of interarea is significantly higher in ventral than in dorsal valves, the opposite result is found for sample A. In the former sample, this higher ventral association is attributed to an irregularity in the attitude of the pedicle indicated by the irregular occurrence of an apical plate not found in specimens of sample A.

5. There is a moderately high degree of linear association between log values of valve width and the area of the adductor- and diductor-scars.

6. A critical examination of Parkinson (1954) shows that the section dealing therein with comparisons of means and variances of ratios of characters must be rejected.

7. From computations of the allometry equation (using reduced major axes) it is seen that in ventral and dorsal valves of sample B, for the two width intervals, and for the characters length and width, only one part of the four estimates of k clearly indicates allometry.

8. The apparent disagreement between these results and those of Parkinson concerning the existence of an increase or a decrease in the estimate of k for width >21.5 mm. might be merely superficial since Parkinson uses composite characters of the shell, whereas only valve characters were dealt with in the present paper.

9. The different estimates of k in the width intervals may be attributed either to environmental or genetic causes. Slight favour is given to a postulated genetic origin by relating the size of the individuals undergoing the shape change to a definite stage of the ontogeny.

ACKNOWLEDGMENTS

This paper, prepared while I was on leave from the Bureau of Mineral Resources, Geology and Geophysics, Canberra, is an appendix of a Ph.D. thesis submitted in the University of London. The work was carried out in the Geology Department of Imperial College, London, during tenure of a Beit Scientific Research Fellowship.

Dr. D. V. Ager and Dr. G. Thomas of Imperial College, London, Professor A. Williams of Queen's University, Belfast, and colleagues in the Bureau have kindly read the manuscript and offered helpful criticism.

LITERATURE CITED

BOUCOT, A. J., 1953, Life and death assemblages among fossils: Am. Jour. Sci., v. 251, p. 25–40, 248.

BURMA, B. H., 1948, Studies in quantitative paleontology: 1. Some aspects of the theory and practice of quantitative invertebrate paleontology: Jour. Paleontology, v. 22, p. 725–761.

COLEMAN, P. J., 1951, *Atrypa* in the Devonian of Western Australia: Jour. Paleontology, v. 25, p. 677–690, pls. 100–102.

COOPER, G. A., 1944, Phylum Brachiopoda *in* H. W. Shimer and R. R. Schrock, Index fossil of North America, p. 277–365, pls. 105–143, John Wiley & Sons Inc., New York.

DEEVEY, E. S., JR., 1947, Life tables for natural populations of animals: Quart. Rev. Biology, v. 22, p. 283–314.

FISHER, R. A., 1950, Statistical methods for research workers, 11th Ed., Edinburgh, Oliver & Boyd.

GUPPY, D. J., A. W. LINDNER, J. H. RATTIGAN, & J. N. CASEY, 1958, The Geology of the Fitzroy Basin, Western Australia: Bur. Min. Resour. Aust. Bull. 36.

KERMACK, K. A., 1954, A biometrical study of *Micraster coranguinum* and *M.* (*Isomicraster*) *senonensis:* Phil. Trans. Roy. Soc. London, ser B, v. 237, p. 375–428.

——, & J. B. S. HALDANE, 1950, Organic correlation and allometry: Biometrika, v. 37, p. 30–41.

KURTÉN, B., 1954, Population dynamics—a new method in paleontology: Jour. Paleontology, v. 28, p. 286–292.

MENARD, H. W., & A. J. BOUCOT, 1951, Experiments on the movement of shells by water: Am. Jour. Sci., v. 249, p. 131–151.

PARKINSON, D., 1952, Allometric growth in *Dielasma hastata* from Treak Cliff, Derbyshire: Geol. Mag., v. 89, p. 201–216.

——, 1954, Quantitative studies of brachiopods from the Lower Carboniferous reef limestones of England. 1. *Schizophoria resupinata* (Martin): Jour. Paleontology, v. 28, p. 367–381.

PERCIVAL, E., 1944, A contribution to the life-history of the brachiopod, *Terebratella inconspicua* Sowerby: Roy. Soc. N. Z. Trans., v. 74, pt. 1, p. 1–23.

RICHARDS, O. W., & A. J. KAVANAGH, 1945, The analysis of growing form, *in* Essays on growth and form presented to D'Arcy Wentworth Thompson, p. 188–230, Clarendon, Oxford.

SCHUCHERT, C., & G. A. COOPER, 1932, Brachiopod genera of the suborders Orthoidea and Pentameroidea: Peabody Mus. Nat. Hist. Mem., v. 4, pt. 1, xii+270 p., 29 pls.

TEICHERT, C., 1949, Observations on stratigraphy and palaeontology of Devonian, western portion of Kimberley Division, Western Australia: Bur. Min. Resour. Aust., Rpt. 2, p. 1–55, 6 pls.

VEEVERS, J. J., 1959, Devonian brachiopods from the Fitzroy Basin, Western Australia: Bur. Min. Res. Australia, Bull. 45.

MANUSCRIPT RECEIVED JULY 5, 1958.

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 902–908, 7 TEXT-FIGS., SEPTEMBER, 1959

THE TYPE SPECIES OF *PRODUCTELLA*, *EMANUELLA*, *CRURITHYRIS* AND *AMBOCOELIA* (BRACHIOPODA)[1]

J. J. VEEVERS
Bureau of Mineral Resources, Geology and Geophysics, Canberra

ABSTRACT—Topotypical material of the Upper Palaeozoic brachiopod genera *Productella* Hall 1867, *Emanuella* Grabau 1925, *Crurithyris* George 1931, and *Ambocoelia* Hall 1860 is described and figured. Special attention is given to internals and shell structure. Taleolae in *Productella* are rare. The lectotype of *Emanuella takwanensis* is chosen. The teeth in *Crurithyris* and *Ambocoelia* are small, unsupported either by dental plates or ridges.

PRODUCTUS SUBACULEATUS MURCHISON 1840, THE TYPE SPECIES OF *PRODUCTELLA* HALL 1857

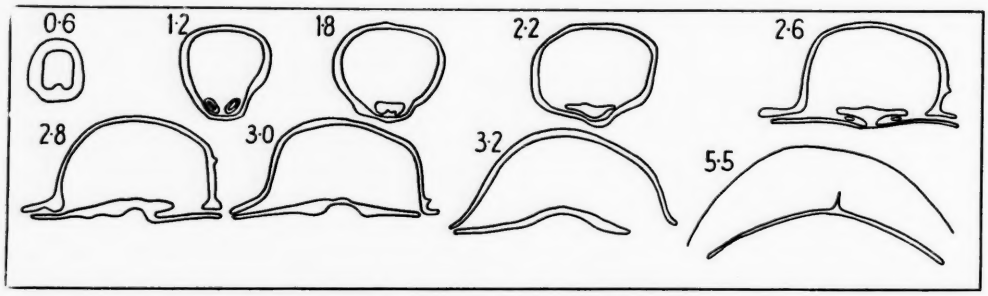
Material.—Twenty-five specimens were collected from the Beaulieu Shales in the "Parisienne" part of the Beaulieu Quarry, near Beaulieu Railway Station and the village of Ferques, Pas de Calais, northwestern France. These specimens agree externally with Murchison's original figures of *Productus subaculeatus* and since Murchison named Ferques as the first locality, there is no doubt that these specimens are topotypical.

Exterior.—The original description (Murchison, 1840) requires no amplification.

Interior.—The ventral valve is provided with tiny teeth (text-fig. 1, section 2.6, fig. 2B), which engage with strong sockets formed on one side by the valve-wall, on the other by the huge base of the cardinal process. The cardinal process is bilobed, with the lobes separated by a deep median sulcus. The posterior depressed median part of the dorsal valve (text-figs. 1,2.8,3.0 and 3.2) internally has shallow grooves on either side of a low median ridge which develops anteriorly into a moderately high, thin, median septum (text-fig. 1, 5.5). In this part, the shell cavity is fairly small.

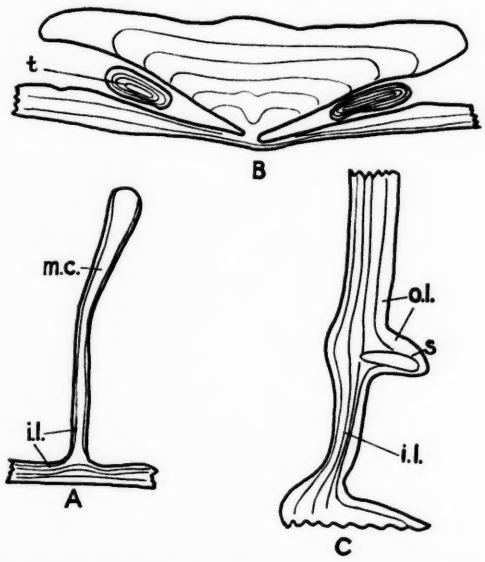
Shell structure.—The outer, as well as the inner layer is well preserved. The outer layer is thin and apparently cryptocrystalline; it lies evenly over the inner layer parallel to the growth laminae except in the vicinity of spines. Text-fig. 2c shows how the outer layer is forced outwards, but with-

[1] Published by permission of the Secretary, Department of National Development.



TEXT-FIG. 1—*Productella subaculeata* (Murchinson). Nine serial transverse sections (×2⅓) of a topotypical specimen with L = 17.3 mm., = 14.8 mm., depth of ventral valve = 9.6 mm. Numbers to left of each section in this and following text-figures refer to the distance in millimeters anterior to posterior extremity of shell.

Section 0.6 shows the prominent median ridge on the dorsal side of the delthyrial cavity. The bilobed cardinal process is seen in sections 1.2 and 1.8, and the teeth and sockets and the base of the process in sections 2.2 and 2.6. The low median ridge flanked by narrow grooves appears in sections 3.0 and 3.2. Finally section 5.5 shows the thin median septum and the small shell cavity.



TEXT-FIG. 2—*Productella subaculeata* (Murchison). Enlargements of parts of sections in text-fig. 1. A, section (×25) through the median septum (section 5.5, text-fig. 1) showing the finely fibrous inner layer (i.l.) and the median core (m.c.) of cryptocrystalline material.

B, section (×15) through the teeth and sockets (section 2.6, text-fig. 1). The minute teeth are composed of concentric growth laminae. The enormous base of the cardinal process has growth laminae nearly parallel to the plane of commissure.

C, section (×15) through right side of ventral valve (section 2.6, text-fig. 1), showing a short entire hollow spine (s) with a *post mortem* infilling of mineral matter. Only the outer layer (o.l.) is involved in the formation of the spine, the parallel growth laminae of the inner layer (i.l.) remaining unaffected.

out a decrease in thickness, to form the hollow spine. The growth laminae of the inner layer remain essentially parallel.

The shell structure of the median septum (text-fig. 2A) recalls in intimate detail that of the homologous feature in a species of *Kayserella* and *Avonia* from the Devonian of the Fitzroy Basin, Western Australia (Veevers, 1959a). The median septum is composed of a median core of cryptocrystalline matter ensheathed by a thin covering of the inner layer.

The teeth and sockets (text-fig. 2B) have a structure denoting regular accretion by the mantle; laminae were deposited uniformly on all sides of the teeth, and uniformly on the ventral side only of the base of the cardinal process.

Taleolae (Williams, 1956) are rare in these specimens Peels of five serially sectioned shells were closely examined, but only few sections showed taleolae. A similar condition was found also in a species of *Productella* from the Carnarvon Basin, Western Australia (Veevers, 1959b).

In view of these observations interest will be attached to future studies of shell structure in other members of *Productella*, for it may be shown that in this group of early productids the pseudopunctate condition was in an incipient stage of development.

NUCLEOSPIRA TAKWANENSIS KAYSER 1883, THE TYPE SPECIES OF *EMANUELLA* GRABAU 1925.

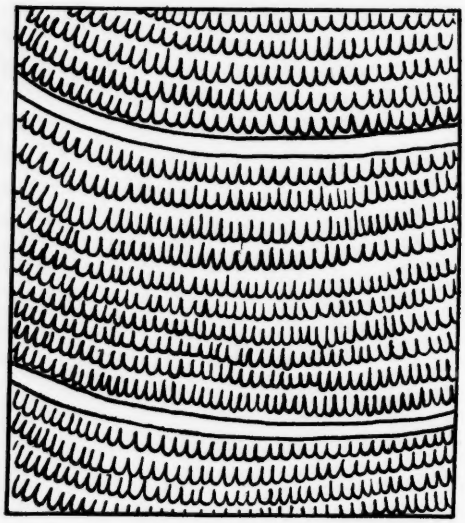
Vandercammen's paper (1956) on the subfamily Ambocoeliinae contains reference to the genera *Emanuella*, *Crurithyris* and *Ambocoelia*. Cause for comment on this paper has naturally arisen from the present study of the type species of these genera. Descriptions of three new species and one new genus of Ambocoeliinae from the Devonian rocks of the Fitzroy Basin, Western Australia (Veevers, 1959a), occasion further comment. I do not propose to comment on Vandercammen's paper here, but refer readers to the longer paper on the Western Australian fossils.

Material.—The twenty-two specimens on which Kayser based his original descriptions were made available on loan by Professor W. O. Dietrich of the Geologish-Paläontologisches Institut, East Berlin. These specimens, with a few exceptions entire shells free of externally adhering sediment, are well preserved in calcite with an infilling matrix of claystone. Although the exteriors of most shells are little worn, the exterior of only one shell shows the characteristic shagreen pattern of minute spinules (see text-fig. 3).

Exterior.—Kayser's description of the exterior requires amplification on two points only. First, the fine details of the spinules are illustrated in text-fig. 3 which shows part of the external surface of the dorsal valve of specimen G-P.I.M.B. 2308. The spinules are arranged in lines concentric

with growth-lines: there are as many as fifteen lines of spinules between adjacent growth-lines. The tiny spinules themselves are joined to their neighbours at their base. Hence the lines of spinules may be considered as indented growth-lamellae.

Secondly, it was found that the lines along the median part of specimens figured in



TEXT-FIG. 3—*Emanuella takwanensis* (Kayser). External view (×50) of the posterior-lateral part of a dorsal valve (G-P.I.M.B.2308) showing regular concentric growth-lines and indented growth laminae.

Kayser's (1883) figures 2,2a,2d,2e,2g of plate 10 are merely superficial cracks and not sulci as Kayser suggested.

Interior.—By means of serial sections of the posterior part of one of the shells (text-figs. 4A, 5) certain details of the interior were revealed.

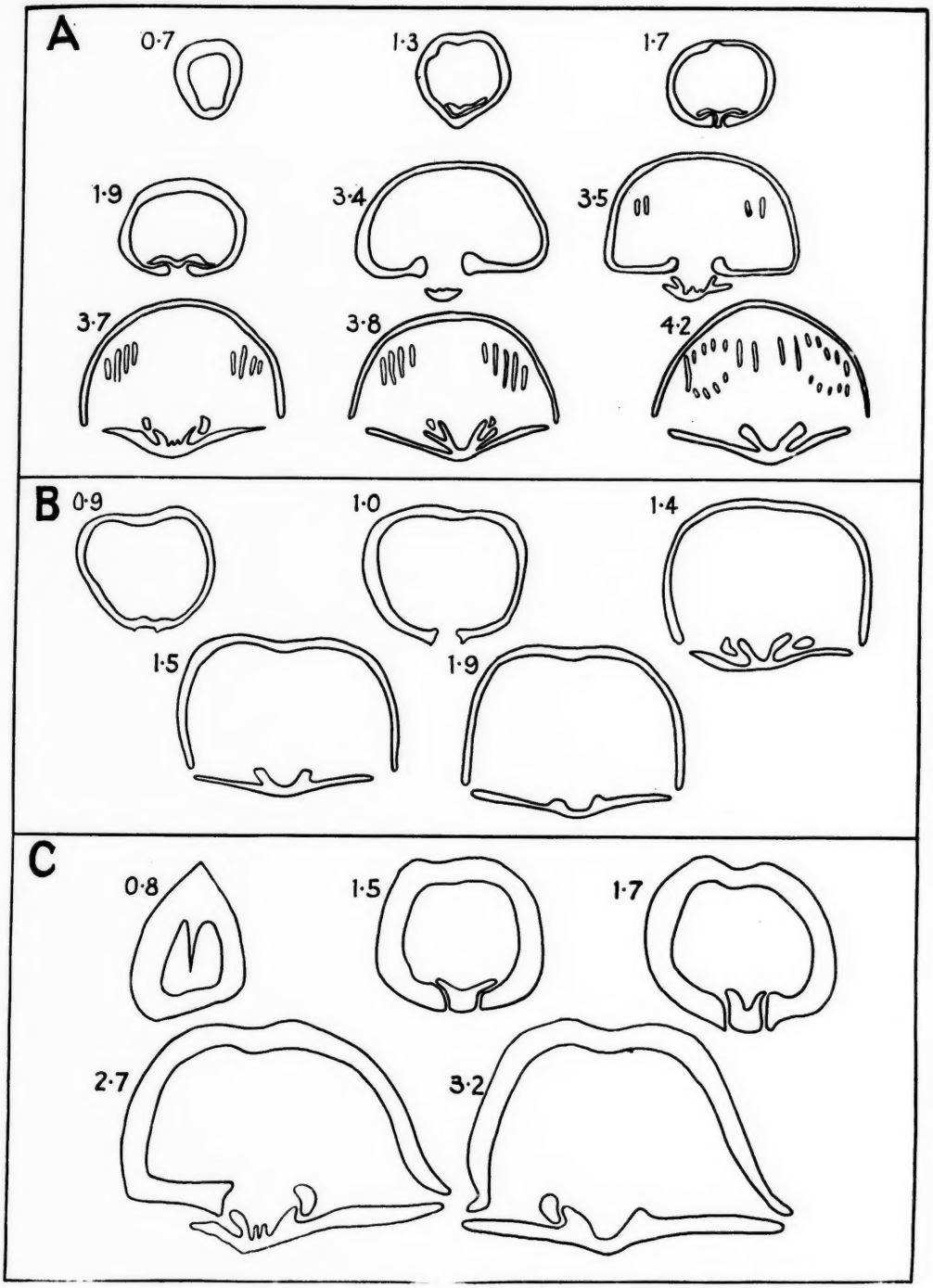
The ventral valve is provided with a well-developed pedicle collar, tiny deltidial plates and small teeth supported by dental ridges. The pedicle collar is a small plate situated in the umbo, protruding anteriorly into, and blocking the posterior part of, the delthyrium. The growth laminae of the anterior parts of the lateral arms of the plate are nearly at right angles to the growth laminae of the dorsal wall of the ventral valve (*see* text-figs. 4A,5, sections 1.7 and 1.9). Deltidial plates are very poorly developed and are simply tiny ridges developed along the delthyrial edges (*see* text-fig. 4A, section 3.4). The teeth and dental ridges are simple thickenings along the delthyrial edges (sections 3.4 to 3.8).

The dorsal valve is provided with a small low tuberculate cardinal process, small chilidial plates, large strong dental sockets supported by short strong crural plates, and apparently simple spiralia. The cardinal process (text-fig. 4A, sections 3.4, 3.5 and 3.7) is a low striated ridge, bilobed anteriorly, separated from the chilidial plates and inner socket plates by shallow narrow grooves. The posterior parts of the dental sockets are formed by the valve-wall and the inner socket plates (section 3.7), but a short distance anteriorly, the outer and inner socket socket plates are raised above the floor on short thick crural plates (section 3.8) to make strong sockets. The crural bases are embedded in the base of these (crural) plates (sections 4.0, 4.2). Only the posterior parts of the spiralia were sectioned. The posterior part of each spiralium consists of eight turns in a simple coil, presumably without a jugum.

Shell structure.—Only the inner shell layer was seen. This is fibrous, impunctate.

The shape of growth laminae in the pedicle plate and in the adjacent valve-wall indicates that this plate originated in the same way as the homologous feature in species of *Emanuella* and *Crurithyris* from the Devonian of Western Australia (Veevers, 1959a), viz., through deposition by the dorsal side only of the umbonal part of the mantle caused by the anterior retreat of the pedicular-outer epithelial junction during early maturity (*see* Williams, 1956, p. 255–258). The growth laminae of the dental sockets (text-fig. 5, section 3.8) indicate that the ventral surfaces of the inner socket plates and the crural plates were positions for the attachment of muscles which resorbed parts of the crural plates and subsequently covered these parts with a thin layer of callus deposit.

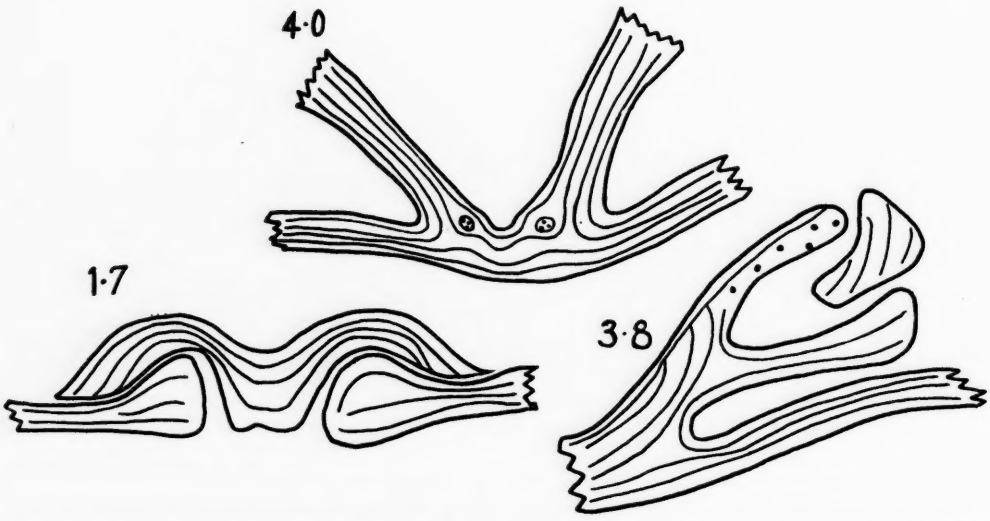
Type.—The specimen illustrated by Kayser (1883) pl. 10, figs. 2,2a,2b,2c, (G-P.I.M.B. 2305) is selected here as lectotype.



TEXT-FIG. *4*—A, *Emanuella takwanensis* (Kayser). Ten transverse serial sections and peels (×3) of one of Kayser's original specimens (G-P.I.M.B. 2323). Its measurements are L = 13.6 mm., W = 13.4 mm. (est.), and T = 9.2 mm.

B, *Crurithyris urii* (Fleming). Five transverse serial sections and peels (×10) of a topotypical specimen, B.M.(N.H.) BB16025.

C, *Ambocoelia umbonata* (Conrad). Five transverse serial sections (×6) of a topotypical specimen, B.M.(N.H.)B9570.



TEXT-FIG. 5—*Emanuella takwanensis* (Kayser). Enlargements of parts of serial sections, two of which appear in text-fig. 4A. The section at 4.0 is ×15, and those at 1.7 and 3.8 are ×20.

Measurements.—

	Plate and Figure No.	Length, mm.	Width, mm.	Thickness, mm.
A. Specimens figured in Kayser (1883)				
Lectotype G-P.I.M.B. 2305	Pl. 10, figs. 2, 2a–c	15.2	16.0	10.0
figured specimen G-P.I.M.B. 2306 (anterior margin worn)	Pl. 10, fig. 2d	13.8	18.7	9.0
figured specimen 2308	Pl. 10, figs. 2e, 2f	17.3	17.6	9.9
figured specimen 2370	Pl. 10, figs. 2g,h	14.5	14.3	9.6
B. Specimens figured in Frech (1911)				
figured specimen 2310	Pl. 7, fig. 5c	13.2	14.2	9.5 (est.)
figured specimen 2311	Pl. 7, fig. 5b	13.7	12.8	7.0 (est.)
C. Other specimens				
specimen 2320	(not figured)	9.6	15.2	8.5
specimen 2316	(not figured)	13.7	12.3	8.5

SPIRIFER URII FLEMING 1828, THE TYPE SPECIES OF *CRURITHYRIS* GEORGE 1931*

Material.—A calcareous shell from the Lower Carboniferous of Lanarkshire, Scotland, B. M. (N. H.) BB16025, G. H. Morton Collection. This specimen is very similar in size and shape to the lectotype selected by George (1931, p. 55) and as the lectotype comes from "(?the D_2–D_3 zone of) the Avonian, Strathaven, Lanarkshire" (George, 1931, p. 56), BB16025 may be considered to be topotypical. Its measurements are as follows: length = 4.0 mm., length of dorsal valve = 3.0 mm., width = 4.1 mm., width of hinge-line = 2.6 mm., and thickness = 2.4 mm.

Exterior.—There are no further details to add to George's redescription.

Interior.—Serial sections of BB16025 are shown in text-fig. 4B. They are rather poor, and only two sections show well-preserved growth laminae. Nevertheless these sections confirm George's description of the interior and also provide some new data.

* Vandercammen (1956, p. 11) errs in listing *Crurithyris amoena* as type species of *Crurithyris*. For original designation, *see* George (1931, p. 43.)

Although the celluloid peel of section 0.9 does not show any trace of growth laminae, it is likely that the shell matter found between the tiny deltidial plates represents the pedicle collar. The deltidial plates lie along the edges of the delthyrium, and, as the umbo of the ventral valve is not strongly inturned in this specimen, the pedicle collar is the only part of the shell which could lie between the deltidial plates. These latter are minute dorsally directed ridges present along the entire edges of the open delthyrium.

The teeth are mere thickenings at the delthyrial angles. They are unsupported by either dental plates or dental ridges.

TEXT-FIG. *6*—*Crurithyris urii* (Fleming). Enlargement (×50) of sections 1.5 of text-fig. 4B.

The dental sockets are strong structures formed by the valve-wall and the strong inner socket plates which continue anteriorly as low crural plates enclosing the crural bases. The growth laminae in section 1.5 (text-fig. 6) indicate that the ventral surface of the crural plates is occupied by muscles in the same fashion as in *Emanuella takwanensis* (Kayser) and in an undescribed species of *Emanuella* from Western Australia. Further anteriorly the crural bases are enclosed very low ridges barely raised above the valve-floor (text-fig. 4B, section 1.9). Still further anteriorly, the shell is completely recrystallized.

ORTHIS UMBONATA CONRAD, THE TYPE SPECIES OF *AMBOCOELIA* HALL (1860)

Material.—An entire calcareous shell, B.M.(N.H.) B9570, from the type locality of Moscow, eastern New York, in the Hamilton Group. Its measurements are as follows: length = 8.7 mm., length of dorsal valve = 6.8 mm., width = 9.4 mm., width of hinge = 8.3 mm., thickness = 5.1 mm. The infilling matrix is pyritic calcite which has

TEXT-FIG. *7*—*Ambocoelia umbonata* (Conrad). Enlargement (×17) of section 1.7, text-fig. 4C, showing growth laminae in the pedicle collar and deltidial plates.

led to the obliteration of the brachial supports.

Exterior.—Nothing can be added to previous descriptions of the exterior.

Interior.—The poor set of five serial sections shown in text-fig. 4C is the best of three prepared sets.

The pedicle collar (text-fig. 4C, sections 1.5 and 1.7, and text-fig. 7) is a short thick narrow plug which seals the posterior part of the delthyrium, the remainder of which is open. Deltidial plates are similar to those found in *E. takwanensis* (Kayser), that is, they are tiny dorsally directed ridges running along the delthyrial edges. The teeth are small, unsupported either by dental plates or by dental ridges.

The cardinal process (text-fig. 4C, section 2.7) is bilobed, deeply notched. Dental sockets are formed simply by the valve-wall and inner socket plates. The crural bases are deeply embedded in the bases of the socket plates, the ventral surface of which is covered by a thin sheet of callus material implying that this surface was used for muscle attachment. The same implication arose from the study of shell structure in *E. takwanensis* (Kayser) and *Crurithyris urii* (Fleming). In these species with posteriorly located adductor muscle fields in the dorsal valve, the thin sheet of callus over the crural plates (or inner socket plates) is almost certainly a deposit of the adductor muscles. However, in *Ambocoelia umbonata* with its anteriorly located adductor muscle field, the position of the callus deposit indicates the broader base of attachment of the diductor muscle, which in most brachiopod species in anchored solely to the cardinal process.

ACKNOWLEDGMENTS

This paper, prepared while I was on leave from the Bureau of Mineral Resources, Geol-

ogy and Geophysics, Canberra, is an appendix of a Ph.D. thesis submitted in the University of London. The work was carried out in the Geology Department of Imperial College, London, during the tenure of a Beit Scientific Research Fellowship.

Collections of *Productella* from northwestern France were secured with the aid of a grant from the Central Research Fund of the University of London.

Dr. H. M. Muir-Wood of the Geology Department, British Museum (Natural History), London, and Professor W. O. Dietrich of the Geologisch-Paläontologisches Institut und Museum, Berlin, kindly lent specimens in their care.

LITERATURE CITED

FRECH, F., 1911, in RICHTHOFEN, F. F., China, v. 5, xii+289 p., 31 pls., Berlin, Reimer.

GEORGE, T. N., 1931, *Ambocoelia* Hall and certain similar British Spiriferidae: Quart. Jour. Geol. Soc. London, v. 87, p. 30–61, pls. 3–5, 3 text-figs.

KAYSER, E., 1883, Devonische Versteinerungen aus dem südwestlichen China, *in* RICHTHOFEN, F. F., China, v. 4, xvi+288, p., 54 pls., Berlin, Reimer.

MURCHISON, R. I., 1840, Sur les roches dévoniennens qui se trouvent dans le Boulonnais: Soc. géol. France Bull., v. 11, p. 229–256, 2 pls.

VANDERCAMMEN, A., 1956, Revision des Ambocoeliinae du Dévonien de la Belgique: Inst. roy. Sci. nat. Belg. Bull., v. 32, no. 43.

VEEVERS, J. J. 1959a, Devonian brachiopods from the Fitzroy Basin, Western Australia: Bur. Min. Res. Australia, Bull. 45.

——, 1959b, Devonian and Carboniferous brachiopods from northwestern Australia: *ibid.*, Bull. 55.

WILLIAMS, A., 1956, The calcareous shell of the Brachiopoda and its importance to their classification: Biol. Reviews, v. 31, p. 243–287, 7 text-figs.

MANUSCRIPT RECEIVED JULY 5, 1958

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 909–914, SEPTEMBER 1959

SYMPOSIUM ON FIFTY YEARS OF PALEONTOLOGY

A HALF CENTURY OF PALEONTOLOGY

CARL O. DUNBAR
Peabody Museum, Yale University

Founding of The Paleontological Society.—At the meeting of The Geological Society in New Haven in 1907 an informal committee of 9 met to formulate plans for organizing a paleontological society. It included Charles Schuchert as chairman, John M. Clarke, F. B. Loomis, W. J. Sinclair, T. W. Stanton, E. O. Ulrich, C. D. Walcott, David White, and S. W. Williston. Early in 1908 this committee addressed a circular to all active paleontologists in America, asking opinions (1) as to the scope of the proposed society, (2) as to whether it should be affiliated with The Geological Society of America, and (3) what form of publication it should adopt. It also outlined a proposed constitution and issued a call for an organizational meeting to be held at the end of the year during the annual meeting of The Geological Society.

At this meeting in Baltimore on December 31, 1908, *The Paleontological Society* was formally organized with 34 charter members of whom 22 were invertebrate paleontologists, 10 were vertebrate paleontologists, and 2 were paleobotanists. John M. Clarke was elected the first president of The Society. By the end of its first full year, on December 31, 1909, membership had increased to 96 and included most of the active paleontologists in North America.

Growth of the profession.—The birth of The Paleontological Society coincided approximately with the discovery of the immensely rich oil fields of the Mid-Continent, and was followed by pheonomenal growth of the petroleum industry in which the use of microfossils in subsurface correlation played an important role. This rapid expansion of applied paleontology in the oil fields led to the organization of The Society of Economic Paleontologists and Mineralogists in 1926. Since then both societies have grown steadily and their combined membership now exceeds 2000. This increase in the number of active American paleontologists by 20-fold in a brief half century is noteworthy.

Facilities for publication.—The expansion of paleontologic activity soon created an urgent need for new outlets for publication. This was met largely by two significant developments. In 1927, during the second year of its existence, the S.E.P.M. launched the JOURNAL OF PALEONTOLOGY, primarily for the description of newly discovered microfossils from the oil fields. For the next 8 years the JOURNAL appeared as an annual volume of about 350 pages and 50 plates. By 1935 a program of cooperation was worked out between the P.S. and The S.E.P.M., whereby The Paleontological Society joined in publication of the JOURNAL. The scope of the JOURNAL was then broadened to cover the whole field of invertebrate paleontology, and with financial support from the A.A.P.G. on the one hand and from The G.S.A. on the other, its size was increased to an average of approximately 800 pages and 100 plates per volume.

A second milestone of progress came with the magnificent bequest of Dr. R. A. F. Penrose to The Geological Society of America out of which came the Memoir Series and the Special Papers of the G.S.A. Previous to this, members of The Paleontological Society had found a limited outlet for short papers in the Bulletin of The G.S.A.; now the Memoirs and the Special Papers could handle works of monographic scope in paleontology. By friendly cooperation between the officers of The Geological Society and The Paleontological Society, short papers of descriptive paleontology were thenceforth assigned to the Journal of Paleontology and longer ones were published by The Geological Society. Within the quarter century since this plan was initiated 72 volumes of paleontological monographs have been published in this way, 43 as Special Papers and 29 as Memoirs of The Geological Society of America.

Mention must also be made of *Contributions from the Cushman Laboratory for Foraminiferal Research*, founded privately in 1925 by Joseph Cushman who had become

the foremost student of the foraminifera and to whose laboratory at Sharon students were flocking from all parts of the world. This serial ran to 25 volumes before Dr. Cushman's death in 1949 and is now continued as Contributions from the Cushman Foundation for Foraminiferal Research.

Improved techniques.—During the half century since the founding of The Paleontological Society improved techniques for the preparation of fossils have gained wide acceptance. The use of acid to free silicified fossils from limestone is not a new technique but it was used almost incidentally until Dr. Cooper at the U. S. National Museum began using it on a massive scale in his study of the Permian faunas of West Texas. By dissovling some 60 tons of large blocks of Permian limestone he has since amassed at the U. S. National Museum a fossil collection without parallel in the annals of paleontology—a collection of some 3,000,000 free specimens many of which show all the shell features as well as if they had been gathered alive from the Permian sea floor. Among other things they reveal assemblages of organisms in position of growth with spines of attachment and other details scarcely possible of preservation in free weathered specimens.

Out of this project grew experience in recognizing types of limestone suitable for etching that had previously been ignored, and as Cooper's work spread over the Ordovician formations in the Southern Appalachians it yielded brachiopods and trilobites of amazing perfection. Knowledge of the fruitfulness of etching techniques spread rapidly from Dr. Cooper's laboratory, and now paleontological institutions all across the country have etching laboratories, and the search for silicified fossils goes on all up and down the geologic column. With growing experience, other acids less harsh than HCl are being used on special materials—acetic and formic acids, for example. The insects and spiders thus recovered by Dr. A. R. Palmer from calcareous nodules in Miocene lake beds in California by the use of formic acid are almost beyond belief.

Other techniques for the mechanical removal of matrix from brachiopods by Dr. Cooper and from trilobites by Dr. Rasetti have also been an inspiration to all of us.

The making of thin sections is not a new technique, but it has become a fine art of general use during the last half century in the study of such groups as fusulines, corals, and nautiloids which are no longer described or identified on the basis of gross external features.

General improvement has been made also in the preparation of illustrations for publication. With better optical equipment, more attention is being given to the art of lighting to bring out the full form and the details of ornamentation of fossil shells. It has become common practice to coat specimens before photographing them, with a thin film of ammonium chloride or magnesium oxide to mask color variations and let lights and shadows bring out the natural relief. During the early decades of this half century it was common practice to use a sublimate of ammonium chloride by blowing together the fumes of HCl and ammonia. This technique has several disadvantages, notably the uncertainty of achieving a perfect balance that will leave a neutral precipitate. Specimens coated with ammonium chloride are likely to suffer later deterioration because of an excess of either acid or alkali in the coating. Burning of a magnesium ribbon produces a white cloud of magnesium oxide that is harmless and is easily removed. It is therefore tending to replace ammonium chloride as a coating medium.

It may be noted parenthetically that such treatment is as useful in the *study* of many specimens as it is in the *preparation of illustrations*, since it commonly brings out details that would otherwise be overlooked.

Paralleling the advances in preparation of illustrations has come general improvement in the printing arts. Full tone illustrations were adopted by the JOURNAL OF PALEONTOLOGY in 1930, and by The Geological Society in 1934. Since then improvements in paper and in halftone screens have permitted halftone reproduction to rival and partly to replace fulltone plates.

Changes in the species concept.—During this half century there has been a significant change in the species concept. Neontologists now recognize a species as a *population*—a population of individuals capable of interbreeding. It may be divisible into subspecies

each of which is a more restricted population sufficiently isolated to have developed distinguishable characteristics yet capable of interbreeding with other subspecies if the barriers were removed. The term *variety* has disappeared as a unit in modern taxonomy.

In applying this concept, paleontologists labor under severe handicaps. Not only is the criterion of interbreeding inapplicable, but we commonly have to deal with scattered individuals that can be recovered from the rocks instead of whole populations. We generally have for study only parts of individuals—the hard parts capable of fossilization—and even these are in many cases fragmentary.

Under these conditions it was common practice during the early days of paleontology to select a few specimens believed, by inspection, to be so much alike as to be conspecific, and to chose one of these, commonly the best preserved, as the *holotype*, the rest being *paratypes*. It is reported of one famous paleontologist of the last century—who shall remain nameless—that having thus selected his types of a new species he threw away all specimens that did not closely agree. In any event, the holotype was generally considered to be the most typical or normal expression of the species, more significant than any other specimen in determining its morphologic characters. Paratypes were considered next in importance since they had been involved in formulation of the concept of the species. Specimens later collected from the type locality were of tertiary importance since they were inherently likely to belong to the species; but if they had been identified by the original author they were considered more authentic than if identified by another. Thus a whole heirarchy of different kinds of types came to be recognized and named, each considered to be somewhat less valid as a specific yardstick than the next above. This fetish reached its climax by 1933 when Frizzell was able to publish a catalogue of 233 terms that had been proposed for types of different ranks in the heirarchy.

This whole scheme collapsed like a house of cards in 1940 when George Simpson published his short but epoch-making paper on *Types in Modern Taxonomy*. Simpson emphasized that in an interbreeding population each individual is as much as any other a part of the species. Therefore a true conceptional image of the species—which he called the *hypodigm*—must encompass the extremes as well as the means of variation within such a population. The holotype, as such, can tell us nothing of the range of individual variation; it may not be even an average example of the species. Its only significance is that of name-bearer; any species that includes this specimen must, of course, bear the valid name of the holotype, but no other kinds of types have any real significance.

The difficulty of applying the modern concept of the species in paleontology is real, and it varies from group to group of organisms. In vertebrate paleontology many species have, of necessity, been based upon a single skeleton—even an incomplete one. Obviously such descriptions are inadequate (and I recall hearing Dr. Romer suggest that a large percentage of the species in vertebrate paleontology are probably synonyms). Trilobites are likewise commonly dismembered and many species have been based on a pygidium or a single cranidium, with no evidence of the morphological changes that may have occurred during ontogeny, or of variation among the members of a population. At the other extreme are groups such as the foraminifera, corals, brachiopods, and ammonites which in favorable localities can be collected in large numbers from a single bed and in which the shells are not only complete but preserve a full record of ontogenetic changes. In such cases evaluation of the range of individual variation can be checked quantitatively by biostatistics.

In actual practice it is neither possible nor useful to examine every individual in a population whether it be a living species or a fossil assemblage. A random sample of numerous individuals will normally represent the entire population closely enough for practical needs. If measurable shell features are then plotted graphically they will give unimodal curves if a single species is represented, and the shapes of the curves will reveal much about the range of variation.

At all events in describing a new species the ideal should be to discover the characteristics of a population. It is not enough

to describe a holotype or to try to represent the mean of a group of paratypes; it is equally important to explore and describe the range of variation as shown by a larger sample of the population. This ideal, like the stars, may often be beyond our reach, but at least we can set our compass by it.

Taxonomic revisions and systematic monographs.—Before the present century paleontology had been concerned largely with discovery and description. The result was a vast, disorganized, and ever growing literature, written in many languages—a literature too vast to be seen or read by any individual. Thus the need grew for bibliographic summaries and catalogues of genera and species. Pioneers in this field were Schuchert's *Synopsis of American Fossil Brachiopoda* in 1897 and Weller's *Bibliographic Index of North American Carboniferous Invertebrates* in 1904. During the last half century bibliographic aids of this sort too numerous to mention individually have appeared, but the need for more continues to grow. Among the most important are Bassler's *Bibliographic Index of American Ordovician and Silurian Fossils* (1915), Hay's *Bibliography and Catalogue of the Fossil Vertebrata of North America* (first edition in 1902 and second edition in 1915), Bassler's and Kellet's *Bibliographic Index of Paleozoic Ostracoda* (1934), Branson's *Bibliographic Index of Permian Invertebrates* (1948) and Ellis's and Messina's colossal *Catalogue of Foraminifera* currently in 52 volumes of approximately 1000 pages each.

After generations of discovery and description, the time had come also for synthesis in the form of monographic study and revision of individual biologic groups. There were pioneers in this field before the close of the last century, as for example, Hall's and Clarke's *Introduction to the Study of the Genera of Paleozoic Brachiopoda* (1892) and Wachsmuth's and Springer's *Crinoidea Camarata* (1897), but the number has grown steadily during this century. To mention only a few we may cite Ruedemann's *Graptolites of New York* (1904 and 1908), Clarke's and Ruedemann's *Eurypterida of New York* (1912), Jackson's *The Phylogeny of the Echini* (1912), Knight's *Paleozoic Gastropod Genera* (1941), Cooper's *Chazyan and Related Brachiopods* (1956), Romer's and Price's *Review of the Pelycosauria* (1940) and Mortensen's *Monograph of the Echinoidea* in 16 royal quarto volumes. There are many others, and yet the need for more continues to grow.

A still broader synthesis of the whole field of paleontology was equally necessary as a general reference work and an aid to the teaching of paleontology. The great pioneer in this field was Karl Alfred von Zittel whose *Handbuch der Paleontologie* appeared in 4 volumes between 1876 and 1893. It was continued in several revisions in Germany. Adapted to English in the form of the Zittel-Eastman *Textbook of Paleontology* in 1900 it was revised in 1913, and for almost half a century has been the "Bible" for American students of fossils. Since it had become badly out of date and in need of revision, a Committee on the Preparation of a Paleontologic Textbook was organized by the council of the Paleontological Society in 1946 under the chairmanship of B. F. Howell. Out of this grew the *Treatise on Invertebrate Paleontology* which came into being under the joint sponsorship of The Paleontographical Society of London, The Paleontological Society, and The Society of Economic Paleontologists and Mineralogists. We were fortunate in persuading Dr. Raymond C. Moore to accept the leadership in organizing and directing this project. With great devotion and immense labor he has secured the cooperation of many of the leading specialists of the world in preparation of a colossal synthesis that is now well-known to paleontologists everywhere. In this achievement the Paleontological Society can take just pride.

A somewhat comparable synthesis began to appear in Germany in 1938 as the *Handbuch der Paläozoologie* under the editorship of Dr. Otto Schindewolf, but World War II intervened after the first few units were published and the project was then abandoned. Its counterpart has since appeared in the French *Traité de Paleontologie* under the editorship of Dr. J. Piveteau.

One outgrowth of all this work has been a reappraisal of the bases of the larger taxonomic groupings in most every group of fossils. Hyatts' classification of the cephalopods, Beecher's orders of trilobites, Schucherts classification of the brachiopods, Brady's classification of the foraminifera,

the older classification of the corals, and many others are under attack or are being largely superceded by new and more complex schemes as our understanding grows.

Out of all this synthesis and taxonomic revision have grown two vexing problems. The first is the enormous increase of genera and higher taxa. For the most part this is the inevitable price of progress. The organic world is probably the most complex phenomenon with which scientists have to deal. Of living creatures there are far more than a million distinct kinds and we have to deal with their ever changing ancestors and trace their evolution throughout the last 500,000,000 years or more. Since "taxonomy is the mirror of evolution" there is no way to make it both simple and precise. As we come to understand more fully this vast record it will become even more complex. The number of species increases both by new discoveries and by the splitting of old species. Genera are likewise split as we strive for greater refinement—*Productus*, for example, once including virtually all the spiny brachiopods of the late Paleozoic, had been split into perhaps 50 genera by 1940, and by now includes some 167 genera. The familiar genus *Fusulina* was split into four in 1877 and by 1940 had become 40 odd genera; today it has become 2 families, divided into several subfamilies and probably 100 genera and subgenera. Higher taxa have likewise been subdivided. Until after 1940 nautiloid cephalods were grouped into Hyatt's 5 suborders; today we have to reckon with 14 orders and 75 families of nautiloids. Of ammonites we now have one order but 8 suborders and 190 families. All the other large groups of invertebrates have suffered a like fate.

Even to the specialist working in a single class or order this complexity has become a burden, and to teacher and student alike it amounts to sheer frustration. During nearly 40 years of trial and error in teaching paleontology to graduate students I look back on the "good old days" with nostalgia, for although I have learned more and more paleontology I am less and less able to transmit that knowledge even to good graduate students. I for one no longer know how to teach paleontology.

At best, of course, this means that we are all driven to more and more narrow specialization. The days are gone when a paleontologist can competently handle whole faunas.

Species, I believe, are objective entities in the living world but in paleontology we have the third dimension—time—and wherever the record is sufficiently complete even specific limits vanish, for no population was ever genetically isolated either from its immediate forebears or its immediate descendants. With local exceptions this is not a serious obstacle because of the many breaks in the record.

Genera on the contrary are at all levels subjective groupings of species and in recent years the pursuit of new genera has, I fear, shared something of the excitement of big game hunting in which the bagging of a trophy is an end in itself. The erection of so many monotypic genera tends to defeat the basic purpose of taxonomy and I wonder sometimes if a bag limit to such game should be established.

A second problem growing out of the extensive taxonomic revision during this generation concerns the discovery that many of the familiar and widely used generic names are synonyms of old and little-used or almost forgotten names. To many it has seemed that the law of priority designed to secure stability of names was having precisely the opposite effect. This brings us to another of the important developments of our times—the revival of the International Commission on Zoological Nomenclature. For many years its headquarters were in the U. S. National Museum where Dr. C. W. Stiles served as its Executive Secretary. During his final illness, however, it ceased to function and for some years was essentially defunct. During this interval a group of biologists and paleontologists at the National Museum initiated plans to set up an American Commission on Zoological Nomenclature to carry on. Before it was actually launched, however, Dr. Stiles having died early in 1941, the International Zoological Congress revived the Commission, transferred its headquarters to London, and selected Dr. Francis Hemming as the new Executive Secretary. The Council of The Paleontological Society thereupon threw its influence to support of the revived International Commission and plans for an

American Commission were abandoned.

With great energy Dr. Hemming set about to get more adequate financial support for the Commission and initiated three types of publication: (1) reprinting of the *Rules* (then out of print); (2) *Bulletins* of the Commission in which impending cases were reviewed so as to give opportunity for any interested parties to be heard before a decision was handed down, and (3) *Opinions* and *Declarations* of the Commission.

The revived Commission at once began to use its plenary powers to set aside the rule of priority upon petition of interested parties, and after hearings, to establish *nomena conservenda*. This led eventually to a fourth type of publication recently distributed in the form of *Official Lists of Nomena Conservenda* and of *Rejected and Invalid Names in Zoological Nomenclature*. I understand also that at its recent meeting, in Copenhagen, the International Congress voted to emend the *Rules* so that a name that has not been used during the past 50 years cannot be revived to replace a junior synonym.

On this issue paleontologists are rather sharply divided, some preferring strict adherence to the rule of priority while others prefer the use of the plenary powers of the Congress to save well-known and widely used names. I happen to belong to the latter school, though I agree that no future generation is likely to be plagued with the revival of old names to the extent that ours has been, since the older literature will soon have been restudied and much of the synonymy will be adjusted.

Looking ahead.—Now that I have surveyed some of the changes in paleontology over the last half century I have been asked to lift the certain on the future. Unfortunately I have no crystal ball.

Undoubtedly some of the most interesting and useful developments will lie in the area that is to be discussed by Dr. Cloud and I will not trespass on his domain.

It should be emphasized, however, that there is still much to do in the discovery and description of the faunas entombed in the rocks. We have only begun to study some of the minor groups, and there are great areas in this country where the faunas are still largely unknown. Even in areas that have been extensively studied, like New York State, critical restudy is needed to make sharper discrimination of species and to tie them to definite stratigraphic positions.

We should learn how to chemically treat certain types of massive limestone so that fossils could be silicified and then freed by etching.

Most of our modern descriptions of fossils are old fashioned, verbose, and wasteful. Now that we have the facilities for making fine illustrations they should be a part of the description, not a supplement to it. It is futile to try to describe the shape of a shell when a picture shows it much better. The illustrations should be made first and the text written with them in view. Indeed, most of the description should be used to emphasize the significance of features shown in the figures. Many of the current specific descriptions would be more effective if reduced to half their verbiage and built around good illustrations.

I do not extoll brevity for its own sake—the purpose of a taxonomic description is to convey understanding and if it fails to do so it is wasteful. Since "a species is a population" it is seldom adequate to figure a single specimen however perfect it may be. Several should be illustrated to display the normal range of individual variation. If this were always done in the original description there would be little need for the endless redescriptions that constitute so much of the bulk of paleontologic literature.

Someone will yet discover important fossils in the Precambrian rocks—probably not in the limestones but in slates. Precambrian animals probably possessed chitinous rather than limy tests and they may have been delicate and thin; such would most likely be preserved as carbonaceous films in black muds. Thus far only one Burgess shale fauna has been discovered in the Cambrian rocks; if a comparable discovery is ever made in the Precambrian slates we will have lifted the curtain on a new act in the drama of Creation.

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 915–925, SEPTEMBER 1959

VERTEBRATE PALEONTOLOGY, 1908–1958

ALFRED SHERWOOD ROMER
Museum of Comparative Zoology, Harvard University

NEITHER the year of the founding of this society nor the present year is of especial significance in the history of vertebrate paleontology. Neither marks the beginning nor the end of any significant period in the history of the subject—at least as far as can be seen when viewed at the present moment. But fifty years is a long time in the history of any discipline, and hence it is worth while to pause briefly and review the happenings of this half century, during which many aspects of the science, from field work to published results, have changed, on the whole, very considerably.

In certain regards field work remains much the same. Perhaps some day science will give us a divining rod—something comparable to a Geiger counter—for locating fossils in the field. But lacking this, a good part of field work today, as 50 years ago, consists of wearing out shoe leather in prospecting beds which we fondly hope will yield fossils. Although the bulldozer is an improvement over the mule and scoop in quarry work, the old-fashioned pick and shovel are still our mainstays in excavating fossils and the plaster-burlap bandaging technique used today had already been developed half a century ago.

However, a major change has been in the field of transportation—the coming of the automobile and, most recently, the four-wheel-drive car, the Jeep or its equivalent. A short time ago I read the field notes of a modest expedition to the West made in the year 1908 after a fashion which was typical of that period. One took a train to the town nearest the proposed collecting field, hired a wagon and team of horses and with them a driver who usually doubled as cook (usually a very poor one). The area which could be covered was strictly limited by the means of transportation. Because of the time consumed by a return to town for replenishing supplies, a party could not go too far from its base. Further, it could not enter—or at least tarry in—any region in which fodder and water for the horses could not be found.

These transportation difficulties did not, of course, exist in thickly-settled western Europe where fossiliferous beds were rather adequately known. Despite such transportation handicaps, many of the major fossil fields of the western United States were already plotted out by 1908. Most of the rest of the world, however, was still a blank. The Karroo of South Africa and the Tertiary beds of Patagonia were the only great areas outside of western Europe and North America in which any major amount of exploration and discovery had then been made.

With the coming of the automobile all was changed. The distances over which one could travel from one's base were greatly increased. There being no longer the necessity of finding grass and water for the horses, previously inaccessible desert areas could be worked. A striking example of the results that could be obtained with automobile transportation (even before the advent of the four-wheel drive), was the highly successful series of American Museum of Natural History expeditions to central Asia in the 1920's. One of the few—very few—fortunate results of the recent World War was the development of the four-wheel-drive vehicle, given which, many areas which had previously been inaccessible because of the rough nature of the terrain could be successfully invaded.

That still more modern development of the last half century, the new-fangled flying machine has also aided in field work. No one can collect a fossil by reaching down from a plane, and although a reconnaissance air view of a potential collecting region is of some value, the territory is traversed at such a rapid rate (unless a helicopter be used) that detailed study is impossible. But photographic mapping by airplane in recent decades gives invaluable aid in regions where decent topographic maps are unavailable—regions which include not merely some of the wilder portions of the globe but much of our own West. The stereoscopic effects possible from study of overlapping shots en-

able one to sleuth out favorable areas of "breaks" even more readily than can be done when actually on the ground. One may often plot out an entire season's work before leaving his office for the field; not merely localities to be visited but also the best trails to reach them can be figured out from the maps. Their only drawback is that one cannot tell whether or not a pasture gate is padlocked.

I may note a personal example of the advantages of the horseless over the horse-drawn vehicle in vertebrate work. A few months ago I had the pleasure of being a member of a party collecting Triassic vertebrates in an Argentinian valley, Ischigualasto. The deposit, covering the valley's area of about 40 square miles, is a remarkably rich one—so rich that one hardly needed to prospect at all for fossils, since they were at hand almost everywhere one looked. Why had this remarkable fossil deposit remained so long unworked? The valley was not unknown; indeed, it had been traversed and the nature of the sediments noted by a competent geologist as far back as 1875. The reason is given in the monograph by that geologist. He had crossed the valley, but crossed it as rapidly as possible, and in the midst of his geological description of this general area inserts an emphatic warning to any future scientific traveller not to tarry in Ischigualasto because there is almost no water and not a blade of grass for the mules. Even with adequate automobile transportation the supply problem was a difficult one; without automobiles, collecting there would have been impossible.

Laboratory preparation, too, has changed over the last half century. Just under 50 years ago Adam Hermann, head of the laboratory at the American Museum of Natural History, and the most knowledgable preparator of his period, published a paper giving in detail the preparation techniques then used. Work with hammer and chisels constituted the greater part of the picture; awls of various shapes were indicated as useful for scraping softer materials and in finishing. Some mention is made of dental tools but the warning is given that they tend to get out of order frequently and should be avoided wherever possible.

Today, hammer, chisel and awl still enter prominently into the preparation picture; but the field of preparation methods has widened greatly. There is a much greater emphasis on finer techniques, using, for example, needles under binocular microscopes. The dental motor, with various accessory parts, is today standard equipment, and small power chisels have entered the picture. A recent development is the use of the Cavitron—a dental instrument working at an ultrasonic speed of vibration which is very useful for "bearing down" through the matrix to the surface of a fossil without the danger of surface damage, present with chisels or the usual grinding devices. New chemical aids are also at hand. Shellac, the one hardening material noted in Hermann's paper is still with us and useful, but newer synthetic materials, mainly with acetone as the solvent, have entered the field for cementing and hardening fossil vertebrates. Hermann mentions the possibility of occasionally using hydrochloric acid in the attempt to soften up a hard matrix. It is, however, only recently that there have been introduced preparation techniques using milder acids, particularly acetic and formic, as developed most especially at the British Museum.

The past half century has seen a very considerable growth in the study of morphological detail by the serial section method, invented by Sollas of Oxford at the turn of the century and developed especially by Stensiö. In this method, the specimen—usually a skull or a fraction thereof—is ground down by successive fractions of a millimeter. After every grinding period the exposed surface is drawn or photographed and the grinding resumed. At the end, the specimen has been totally destroyed but there remains a record of photographs or drawings which can be enlarged and reproduced by cut-out wax plates so that the fossil can be reconstructed at any magnification wished, just as an embryologist may reconstruct an embryo from serial sections prepared by the microtome. This serial section method has been able to give us in recent decades intimate knowledge of the morphology of complicated cranial structures which could not have been obtained by any normal means of preparation. The only unsatisfactory part of the process is the fact that if

there is any imperfection in the drawings or photographs, one can never go back to the original. I have been able to add one improvement to this method—the use of peels. The paleobotanists have long had the practice of studying coal balls by grinding down a smooth surface, etching this surface with hydrochloric acid (which eats away all materials except carbon) and then, after washing, pouring on a thin film of cellulose dissolved in acetone. When this film hardens, it may be peeled off, bringing with it the cell designs left in carbon on the etched surface. It once seemed improbable to me that this method could be used for vertebrate fossil specimens, since we do not have in our material this strong carbon versus non-carbon contrast upon which hydrochloric acid etching works so successfully. However, I tried the experiment many years ago and found, to my delight, that etching produced a softening of the entire fossil surface, so that the peel gives a perfect representation of the section as a whole—and gives us, hence, an accurate, permanent record of the entire fossil.

Much more important, however, than questions of changes or advances in field or laboratory methods is that of the scientific work which results from this collection and preparation. As a first object of interest, has there been a change in the quantity of work done in the field? Some areas of science, such as nuclear physics or biochemistry, are relatively recent developments, currently expanding rapidly. As an old and established subject a rapid growth of this sort would not be expected in vertebrate paleontology; but a cursory view of the evidence indicates that there has been considerable expansion during the past half century. I have available bibliographies for the year 1908 and for 1957 (none for 1958 itself is yet available). Neither is complete, but both are rather comprehensive and certainly include all major works published during the year covered, and many of the minor ones, as well. As a crude index of activity I have counted up the number of workers who published one or more papers on vertebrate paleontology during the years studied. To be sure, a fraction of the people publishing in any given year will be individuals only partially interested in vertebrate paleontology; but since only a part of such peripheral workers will publish during a given year, the number of authors counted probably represents fairly accurately the total number of people (including "fractional" ones) who were at work on the subject.

In 1908, my bibliographic source lists only 76 people, the world over, who published papers in vertebrate paleontology. Last year, papers were published by 309 workers. This is almost exactly four times the earlier figure, indicating a healthy, although not spectacular, growth of interest in the field.

The distribution of these workers by geographical areas is interesting and significant. In 1908, almost the entire output was in western Europe and North America. Forty European workers published papers; of the 40 only one was a Russian; practically all the others were concentrated in Germany, England and France. Thirty-four North Americans published, one a Canadian, the others in the United States. All the rest of the world was practically barren of vertebrate workers. The only exceptions were one South African author (Robert Broom, of course), and one Argentinian (Florentino Ameghino).

Very different is the current situation. In 1908, as we have seen, the United States produced close to half of the total publication in the field. Our country was without question the leading nation in vertebrate paleontology—this due, quite surely, not to any extra ability on the part of our workers but to the fact that our resources in fossil materials were the greatest of any region in the world. Today our position is much less prominent. Currently, 78 North American authors (several Canadians are included) are publishing in the field, this figure being somewhat over double that of 1908. But the average world increase, we have seen, was four times the earlier figure; relatively, we are falling behind.

Europe has seen the greatest increase of interest. In 1957, 183 workers are listed in my bibliographic source from that continent, a figure four-and-a-half times that of 1908. In the distribution of these workers by country, England, France and Germany are still well represented, although the last has not re-attained its once essentially dominant position. But other countries which

had little or no representation 50 years ago have since sprung up as active centers of vertebrate work and a considerable number of workers are to be found in such areas as the Scandinavian countries, Spain, and Poland. Most interesting is the rise of vertebrate paleontology in Russia. In 1908, we have noted, only one Russian figures in the bibliography. We customarily think of Russian science as being concentrated on technological and economic affairs and would expect that such a "pure" science as vertebrate paleontology would be completely neglected. The case is quite otherwise. In the 1957 bibliography the names of 33 Russian scientists appear!

Equally striking is the rise of interest in other countries. In South Africa were found last year the names of 11 workers instead of the one of 50 years ago; in South America 8 instead of one. Japan, India, Australia, Turkey, Israel and Madagascar are countries where workers are publishing today but were entirely unrepresented 50 years ago. Most striking of extra-European areas is China, where the names of 15 workers appear in the last bibliography.

To sum up: The United States and the major western European countries have advanced moderately in quantity of vertebrate publication, but no longer dominate the picture. Every region of the world has entered in, and most interesting is the upsurge of interest in those great Communist countries, Russia and China.

More important, however, than quantity of scientific output is its quality. Has the general run of publications in the vertebrate field assumed a different character during the half century? Let us consider the various types of scientific work which might be, and have been, pursued.

We are dealing with the life of the past—with once living animals—and as far as possible we should treat these extinct forms in as scientific a fashion as in the case of a modern animal. In the case of a modern form it has, of course, first to be given a name. Then should follow studies of its structure and physiology and function in general, together with its relation to its environment—its ecology—and, finally, its classification and position in the evolutionary picture. Quite naturally we cannot study a fossil form as thoroughly in every regard as in the case of a modern one. But we should be as thorough as possible.

First, the animal needs a name and at least a minimum description necessary to make it legal in a taxonomic sense. In some cases the material may be so poor that little more is possible. But unfortunately we find amongst paleontologists, as amongst systematic workers in modern groups, some who feel that their duty is done if they have immortalized themselves by the description, in minimum fashion, of new species, when a far better job might have been done. Has the number of such workers decreased during the past half century? Perhaps; but there appears to be in systematic listings a steadily increasing number of names of little value, cluttering up the record, and obscuring the paleontological picture. For example, new specific names have not infrequently been given to isolated shark teeth in cases where teeth obviously belonging to a similar form have already been described from the same horizon or area. Anyone with the slightest zoological knowledge knows that the individual teeth of sharks vary from part to part of the mouth, and it is highly probable that many forms named in this fashion are synonyms of species already in the literature. But this is usually impossible of proof unless (as quite rarely happens) a complete dentition is discovered. Again, to cite a specific example, Cope many years ago named several species of lungfish on the basis of isolated scales from the Mazon Creek (Illinois) Carboniferous shales; Hay later added to the confusion by describing several more species from this same bed, basing his specific differences merely on scale shape and size. As a result, one gets the impression from the literature that close to a dozen species of the same genus of lungfish were living in this one small area at the same time. Even Hay, himself, a great enthusiast for species making, was embarrassed, suggesting that perhaps the Mazon Creek beds represented an estuary common to a dozen or so streams, each with a different species of lungfish in it! What are we to do in cases of this sort? I suggested long ago as a good working rule, that:

If from a given horizon and area one species of a genus had already been described,

no further species should be named unless they can definitely be shown to differ from the one first named; and that if despite this, further species are named without proper diagnostic characters, they should be considered as synonyms of the one first named.

I hope that descriptive work of this disreputable type is on the decrease; but I have no statistics to show this and I am afraid that the free-wheeling species-maker will be with us to some extent as long as human nature remains unchanged and editors are lax.

One important change, however, has come into operation, in the area of taxonomic work, during the last half century. In earlier years the all important specimen of the species was the type: a sort of enthroned little god, in the image of which all other individuals of the species were supposed to have been made. We are now coming to quite a different position—one in which the type may be of relatively little importance, except as being something to which a name may be attached, and what we must consider is the population as a whole—the hypodigm, to use Simpson's term. We are dealing, supposedly, with animals, not with names. This newer concept is altering our treatment of animal groups in monographic treatments or "revisions." Formerly, a work of this sort would have as its base a listing of the previously named species and their type specimens. This would be followed, mainly, by an attempt to cluster other known material around these names. Properly, such work should be—and currently often is—done by an opposite method. All known material should be reviewed, and assembled into populations marked by common morphological characters. Only then should the matter of nomenclature be considered, by checking as to what names already in existence will apply to one population or another and giving new names to those which lack them.

With current de-emphasis on types, I hope that there will be a decrease in the establishing of neotypes. The excuse for their creation is the loss of the original holotype and the supposed necessity of setting up another object of veneration in place of the lost idol. I fail altogether to see the necessity for this sort of nonsense (other than the attempt to heighten the importance of some museum's collections). Either the original description was good enough so that an animal can be properly identified, in which case there is no need for a new type, or the original description was so inadequate that you cannot identify an animal by it—in which case how does the establisher of a neotype know that his specimen had anything to do with that which was in front of the eyes of the original describer? I have had bitter personal experience with at least one neotype which had been set up to replace a lost Permian specimen of Cope's. Study of the neotype showed that it represented a brand new genus of pelycosaurian reptile and in consequence I based a new genus on the name of the species to which the neotype had been referred. However, going over Cope's original description later, it became apparent that the lost type (unfigured) did not belong to the same kind of animal as the neotype; in fact it wasn't a reptile at all, but rather surely the pelvic girdle of the amphibian *Eryops!*

Basic in the study of any fossil vertebrate is a careful study of its morphology. Even nomenclature cannot properly be done unless morphology is carefully considered so that the supposedly new form can be compared with related animals. Above and beyond the routine business of giving it a name, nearly everything that we can possibly know about a vertebrate fossil must come basically from a study of its skeletal anatomy. Fortunately the science at its inception got off to a good start in this important area. The three major figures in the general period of its founding a century and a half ago were Cuvier, who worked mainly on fossil mammals, Agassiz, the first serious student of fossil fishes, and Owen, whose work lay in great measure among the reptiles. All three were exceedingly competent zoologists, capable of considering their materials as once living animals rather than drab, dead pieces of bone, and two of them were outstanding anatomists. We were almost as fortunate in the early days of the science in our own country, at a somewhat later period. Here Leidy, Cope and Marsh were the trinity of major founders. Leidy and Cope were both excellent zoologists and anatomists; Marsh, whose training had

been mainly in hard rock geology, lacked this background but became a man of money and was able to hire talented anatomists (such as Williston and Baur) to make up for his own deficiencies.

On the whole, the standards of anatomical description set by the early leaders have been maintained by a large proportion of paleontologists; sound morphological descriptions have been given in a large proportion of the cases where material was sufficient to allow it. And in many cases in recent decades the levels of morphological description has even gone far beyond the standards of earlier years; with careful, minute, preparation, and often with the aid of serial section reconstructions, the descriptions—particularly of cranial structures—have in many cases been of as high a standard as has been attained for recent animals of any sort. Work of this type is very important, for we have come to realize that the relationships of animals may be more confidently based upon knowledge of internal structures—far removed from areas of ready adaptation to food or environment—than upon more superficial characteristics. As Americans, however, we can claim relatively little credit for such advances, for most have taken place through the work of such European scientists as Watson and Stensiö.

Such progress has been less conspicuous in the case of mammals than with other vertebrate groups, and relatively little anatomical work of a broad—or deep—nature is being done in this area. The reasons are not far to seek. One is the lesser amount of interesting variation in the skeleton of mammals (except for the monotremes), as compared with other classes of vertebrates. Braincase structure, however is of potential importance in mammal classification. Some good pieces of work have been done in this field, but in general even skull structure is neglected by mammalian paleontologists; for example, the fine monographs by Scott on the White River fauna have illustrations in which the braincases are for the most part merely artistically shaded drawings in which little can be made out of foramina or other significant anatomical features.

A major reason for the relatively low level of mammalian work is that in this class of vertebrates there is an easy short cut to identification and description of species—the molar teeth. In other vertebrate groups the teeth are often of simple construction and do not vary greatly within a given group; hence the worker on reptiles, amphibians, or fish must generally make a thorough examination of the skeleton as a whole before reaching conclusions as to the nature of the animal. In mammals the teeth—the hardest part of the skeleton and hence most frequently preserved—have, in the cheek region, complicated and variable patterns which are in many cases highly distinctive of the genus and species. As a result, many papers in mammalian paleontology are confined almost entirely to the discussion of the cheek tooth patterns, even when abundant material of other parts of the skeleton is present. I sometimes accuse my friends amongst the mammalian paleontologists of envisaging their pets as consisting only of cheek teeth and thinking that mammalian evolution consists merely of a pair of parent cheek teeth having intercourse and producing the baby cheek tooth which becomes the next step in the phylogenetic series. They deny this; but privately will sometimes admit that this picture is not far from the truth.

In all too many instances the quality of recent work in description of vertebrate materials in other areas as well as that of mammals has tended to slip well below that of earlier writers. A major cause is an increase during the present century in the number of workers who consider themselves paleontologists but have had a training in geological matters purely, are hence frequently ignorant of even the most elementary zoological concepts, and as a consequence produce work which is not merely superficial but may contain confusing if sometimes amusing errors. For example, the describer of the skull of a large carnivorous dinosaur noted that the teeth showed very little evidence of wear. From this the author, probably learned in geological matters but ignorant of zoological ones, concluded that the animal must have lived on relatively soft food and hence probably confined his activities to scavenging rotting cadavers. Had the man realized that, unlike himself, reptiles shed their teeth frequently, this er-

ror (which has persisted in the literature) would never have been made. All that the specimen indicates is that the animal, when he died, had not had much to eat since he had last shed and replaced his teeth (quite possibly starvation may have been the reason for his decease)! Again, a number of years ago I received a healthy ribbing, as an American, on meeting a group of European paleontologists because of the recent publication in this country of a paper by a geologically trained writer in which a fossil amphibian was described as having, like a mammal, a chain of three auditory ossicles, rather than the one element proper to lower vertebrates. Had the writer had a reasonable training in comparative anatomy he could have seen from his material, as my European friends (and I also) were able to do from his figures, that two of the three supposed auditory elements were really broken portions of the palatal apparatus of the creature.

Sound morphological study of skeletal remains is basic in the description of paleontological material in the vertebrate field and must of necessity continue to be of major interest. But as in the case of a living animal the skeleton does not go too far toward giving us the complete story. We wish to know about the animal's functions, about his mode of life, his habits and behavior—to put it crudely but clearly, how he goes about his business of *being* an animal. Paleontologists can press on to a certain degree in these directions, although the evidence is, of course, much more tenuous than can be gained in the case of a living animal—and in consequence, to me, the quest is much more interesting and tantalizing. From the skeleton we can to a very considerable degree restore other portions of the animal's anatomy—his musculature, cranial nerves, the general contours of his brain, his sense organs. From these data and from the build of teeth and limbs we can in many cases get some idea of his mode of life. Still further evidence can be gained from a study of the surroundings in which the animal lived—or, at least, those in which he died and was buried. The nature of the other animal remains and those of plants in the sediments can build up a picture of the biologic environment in which he lived and give suggestions as to his enemies, competitors, and food supply. Knowledge of the totality of animals and plants plus the nature of the sediments can further give us strong suggestions as to the physical environment in which he spent his life. These areas of paleobiology were little developed half a century ago and, despite progress, are still very much in their infancy.

A side-product of the attempt to study faunas as a whole lies in a consideration of the spatial distribution of these faunas and of faunal migrations. In this area we have made considerable progress over the past half century, particularly with regard to the distribution of Tertiary mammals. Half a century ago land bridges were all the rage. If all the bridges then advocated for the distribution of one type of vertebrate or another during the Tertiary had been assembled into a single unit, the oceans of the world would have resembled a spider web with land bridges crisscrossing each other every here and there—in fact, creating such confusion that traffic difficulties would have surely been present at various intersections had all the bridges really existed. A major step forward in our understanding of the Tertiary distribution was accomplished by the publication of Matthew's paper of 1915 on "Climate and Evolution." His contributions to the history of climates are suspect, but were a minor portion of the work. His major contribution was the demonstration that existing continental connections plus a make and break at Bering Straits and breaks of varied duration between the northern land masses and southern continents would account reasonably for nearly all distributions of Tertiary mammals. This type of work has been continued by Simpson and others, and our pictures of Tertiary vertebrate distributions are assuming clear shape. For the older periods the situation is not yet clear and it will be long before (if ever) we can be at all sure of continental relationships in the early Mesozoic and Paleozoic. Despite the fact that I was brought up with a fundamentalist belief in continental fixity, I grow, with the years, more and more skeptical of the credo that the Atlantic Ocean came into being during the original Seven Days.

From an elementary stage in the compila-

tion of faunal lists, there may derive a secondary by-product—the use of fossils as an aid to stratigraphy. Faunal lists may be matched, correlations made, stratigraphic columns built up. For the most part such work devolves on invertebrate paleontologists; but in certain regions—such as the Karroo of South Africa or the Tertiaries of our Western states—reliance must be placed on the vertebrate evidence. We are glad to be able to be of service to our geological colleagues. Some vertebrate workers, however, feel that major importance should be given to this type of service, to "justify our existence" in the eyes of geologists.

This is an attitude of dubious value as regards the scientific repute of vertebrate paleontology. In performing these functions, the paleontologist is not operating as a scientist in his own right. He is serving as a technical assistant to the scientist, in much the way that a mathematician may be hired to work out computations for an astronomer, or a chemist employed to run analyses for an endocrinologist. Functioning in this fashion, he represents an inferior form of scientific life.

Further, such work, as often performed is geology, not paleontology—a subject, one may remind oneself, having to do with the life of the past. It is strata and lists of names of animals with which one is concerned in work of this type. The animals themselves are frequently of no concern whatever. Both in vertebrate and invertebrate fields one might in many cases be dealing just as well with assorted types of nuts and bolts as with animals, so long as these can furnish stratigraphic evidence. If one is tempted to challenge this statement, I need only refer to the case of the conodonts. These, I gather, are fossils which are very useful in Paleozoic correlation; but what stratigraphic worker cares what a conodont is, or, in fact, has any idea what a conodont might be?

Paleontology had become a flourishing science before the acceptance of the evolutionary theory (it is a curious and embarrassing fact that the great early leaders in vertebrate paleontology refused to accept evolution). However, evolution is now, and has been for the greater part of a century, the guiding light in the whole field of vertebrate paleontology. Much of the interest in paleontological work has been the gradual filling in of family "trees." Much had already been accomplished fifty years ago. Among placental mammals, the broad outlines of the evolution of many of the Tertiary groups were fairly clear fifty years ago, and while many new and interesting forms have since been discovered and while conceptions of inter- and intra-ordinal relationships have been modified in various cases, advances have not been major ones; in general, the work has been the comforting filling-in of the outlines already established. Our knowledge of Paleocene mammals is still confined, for the most part, to North America. Forty or fifty years ago there was the fond hope (as expressed in Matthew's "Climate and Evolution") that the answer to the origin of the major placental groups which flourished from the Eocene on was to be found in the Paleocene of Asia; but despite the interesting discoveries made in Central Asia by the American Museum expeditions of the 20's, this hope was not realized. Instead, it was found that the most conspicuous element of the Paleocene fauna of that region consisted of ancestral members of the ungulate group later characteristic of South America! Studies by Simpson have given greater clarity to our knowledge of the evolution of Mesozoic mammals; but except for the discovery of a few Cretaceous placentals in Mongolia and finds in the lower Cretaceous of Texas and in the "Liassic" fissure deposits of the west of England, little new material of Mesozoic mammals has been discovered during the present century.

As regards reptiles, we already had a fairly adequate acquaintance with the "classic" types of this group—dinosaurs, pterosaurs, crocodiles, ichthyosaurs, plesiosaurs, and so forth—fifty years ago. Some additions, but few of major importance, have been made to our knowledge of these groups. On the other hand, we have vastly increased our understanding of a number of other reptilian types, such as the more archaic reptiles of the late Paleozoic, the rhynchosaurs, pseudosuchians and, most especially, the mammal-like therapsids, where Broom, Watson and others have advanced our knowledge greatly. As regards amphibians, not much

has been added to our meager store of information of fifty years ago regarding the origin of the modern groups (Piveteau's discovery of an archaic Triassic frog from Madagascar is a major exception). But, on the other hand, we know vastly more about the older amphibians of the later Paleozoic and Triassic than we did half a century ago. Basic in advancing this field were Watson's two major papers on labyrinthodont evolution of 1919 and 1926; he and a number of other workers have made additional contributions of importance. Our knowledge of Carboniferous and Permian amphibians is far from complete, but much of the general outline of the story can be much better told today than was formerly the case, and the discovery of archaic amphibians in the late Devonian of Greenland has filled in a major "missing link."

A little over fifty years ago Smith-Woodward finished his four volume catalogue of fossil fishes, a masterly summary of our knowledge of extinct fishes up to that date. Much of the fish work up to and including this period was (literally) of a superficial nature—consisting mainly of a description of the surface characteristics of the fossils found, with relatively little attention to significant internal anatomy. Presently, however, study of fossil fishes was carried to a new high level by the beginning of the researches of Stensiö who, not satisfied with such superficial treatment, insisted on a thorough study of significant morphological details and a careful consideration of the phylogenetic significance of such structures. Fifty years ago such early fish groups as the placoderms and ostracoderms, were poorly known and puzzling. Many of them were forms with good bony skeletons, whereas we then felt confident that really ancestral types should be cartilaginous forms like sharks and cyclostomes. Today, the subject has been revolutionized; bony forms are truly primitive, cartilaginous types derived, not the other way around. We have advanced far in our knowledge of early fish history. However, many of the earliest steps are still obscure—to be revealed some day, we hope, in Silurian and Ordovician strata as yet unexplored. But while our knowledge of lower fishes has advanced greatly, the same cannot be said of the highest of fishes —the teleosts. We know little more of the evolution of these abundant modern forms than we did half a century ago.

Vertebrate paleontologists have not been concerned with merely plotting the factual data on the evolution of vertebrate groups; they have been interested in the evolutionary patterns that have been revealed and in the contributions which might be made to evolutionary theory through study of these patterns. In earlier decades they were accused—and sometimes rightly accused—of adhering to such mystical and not-too-scientific theories as orthogenesis and Osborn's "aristogenesis." When, however, at the close of the last war, a series of conferences of geneticists, paleontologists, and systematists were held, it was discovered that the beliefs of all three groups were in substantial agreement. Out of the meeting of these various disciplines there has emerged a synthesis of observations and beliefs which have resulted in a modern theory of evolution. In this, Darwin's idea of natural selection is basic, but to this has been added the data revealed by population genetics, the evidence as to speciation seen by observant systematists, and the data regarding actual phylogenetic patterns contributed by the vertebrate paleontologists.

We have, then, made considerable progress in vertebrate paleontology during the past half century. What will the future bring us? Given conditions of peace and prosperity—in which alone a "pure" science such as vertebrate paleontology can flourish—continued advance may be expected. Unlike many sciences, where the interesting and important problems can be sought out and tackled immediately, paleontologists must in great measure wait on chance discoveries (fortunately for most of us, intellect alone will not suffice if materials are undiscovered). Many exciting finds are sure to be made in the future, as in the past. One can hope that high standards of morphological work will be maintained or even improved upon (assuming that proper training may be given to future workers). And most especially, I expect, more and more attention will be paid in the future to ecological and other broadly biological matters, rounding out the story of the life of past ages.

But much of the question as to whether

the future of vertebrate paleontology is to be a success or a failure depends upon the position which vertebrate paleontology is to assume amongst scientific disciplines; by whom scientists in this field are to be supported, in what atmosphere students of the subject are to be trained. It is maintained that paleontology is, or should be, an independent discipline, deriving from both biology and geology but not centered in either. This is a proud claim but a dangerous position. Can we really achieve independence? Paleontology may be a separate discipline, but very definitely not a major one —particularly not as regards the vertebrate paleontologists. We may compare ourselves to the members of the Hyracoidea, the conies of scripture, a group often discussed by vertebrate workers. They are a separate, independent order of mammals, related to those distinguished animals, the Proboscidea and Sirenia. But of the conies, the Old Testament says: "They are a feeble folk, which hideth amongst the rocks." We too are a feeble folk. Positions in which a man may devote himself entirely to vertebrate paleontology are very few in this country, and, as a matter of fact, anywhere in the world. A vertebrate paleontologist can only flourish in a situation in which a museum with an adequate collection is available; such places are few in number. How much expansion can be expected in the future? If one were starting a new university today, would the authorities consider starting an expensive vertebrate collection in order to hire a vertebrate paleontologist as a necessary member of the staff? Hardly. Such collections are luxuries; vertebrate paleontologists, too, are luxuries rather than essential elements in the university community.

As far as I am aware, only at Berkeley does one find a discrete department of paleontology. In general a vertebrate paleontologist must ally himself with one of the two most closely related fields, biology or geology. But whichever one of the two is chosen by or for him, he is in any event destined to be considered a peripheral member of the group. In theory, perhaps, a vertebrate paleontologist should endeavor to compass the entire range of both these major disciplines. But to anyone not possessed of supernatural mental ability, it is impossible to be knowledgeable in the entire spectrum from biochemistry and biophysics through the various biological and geological disciplines to geophysics and geochemistry at the opposite extreme. It just can't be done.

To be sure, vertebrate paleontology can make valuable contributions to either biology or geology. The biologist often does, or should, think in evolutionary terms, but in the absence of paleontology there is no depth to his evolutionary picture; it is paleontology which can alone give him a time dimension. Again, vertebrate anatomy is a subject invaluable for much of biologic work, and today the greatest interest in the subject is to be found amongst vertebrate paleontologists, various of whom are successful teachers of this discipline. To geology, as well, vertebrate paleontology can bear gifts. The evolution of vertebrates is an essential part of the picture of historical geology, and this story is one of fascinating interest to elementary students. In addition the vertebrate paleontologist, as we have noted (but noted with a word of warning) can contribute to stratigraphy.

A vertebrate paleontologist, then, may well be associated with and useful to either a department of biology or one of geology. We find members of our little group of feeble folk currently associated with both fields, in a majority of cases the association being with geology departments. Well and good. But what about the training of the vertebrate paleontologists of the next generation? What sort of a background should they have and where can they best get it?

The answer, I think, is a clear and definite one. The training of a vertebrate paleontologist should be primarily biological. A student of our subject, to be sure, should have a basic knowledge of geological processes and should have training in stratigraphy and sedimentation. Beyond that point emphasis should be on the biological side of the picture. It is sometimes suggested that a vertebrate paleontologist might be trained primarily as a geologist but with a few courses in biology. Closely comparable is the matter of the proper training of the geophysicist. Would one recommend that a geophysicist be trained primarily in geology, but then be allowed to take a few elementary courses in physics? On the contrary; a

geophysicist should be a person adequately trained in physics, although with an interest in the application of physics to the earth. Similarly, a vertebrate paleontologist, in order to make the most of the possibilities before him, should be primarily and soundly trained as a biologist and only secondarily take work in the field of geology.

Half a century ago such a proposed free crossing of departmental boundaries was next to impossible. The areas were marked off by tall fences (and I can still feel, *a tergo*, the impressions made on—or rather in—me by having to roost for many years atop such a high picket fence). Today, however, boundaries are breaking down, divisions between disciplines are tending to become faint. Physics merges into chemistry; chemistry and physics merge into biology and geology; paleontologists, invertebrate and vertebrate alike, bridge the gap between geology and biology. The once high barriers are now low or non-existent and in such a neutral zone vertebrate paleontologists, I fondly hope, may continue to live a peaceful —if somewhat precarious—existence, in friendly community with their geological and biological neighbors.

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 926–962, 16 TEXT-FIGS., SEPTEMBER 1959

PALEOECOLOGY—RETROSPECT AND PROSPECT[1]

PRESTON E. CLOUD, JR.[2]

"Men do generally too much slight and pass over these records of antiquity which Nature have left as monuments and heiroglyphick characters of preceding transactions."
Robert Hooke, 1635–1703

"Every species has three maxima of development.—depth, in geographic space, in time."
Manxman Edward Forbes, 1844

"The mere compilation of facts poses questions rather than answering them."
George Gaylord Simpson, 1953

ABSTRACT—Although paleoecology has roots in the observations of pre-Christian scholars, consciously paleoecological inquiry is barely more than 100 years old. Equally a part of paleontology and a unifying interdisciplinary department within the wider realms of geology, it now enjoys significant interplay over a broad range of advancing science.

The objectives of paleoecology are to understand and to interpret in mutual interrelation, the life processes, sociology, behavior, habitat conditions, biogeography, and evolution of pre-historic organisms, communities, and biotas. These aims can be achieved only in part by the indispensable methods of classical natural history. The scope and rate of progress depend also on the imaginative supplementation of such methods with the tools, liberating concepts, and data of geochemistry, sedimentology, oceanology, and climatology—under the cohesive principles of parallel and proportionate relationships, and in biological perspective.

Paleoecologists need to differentiate between the ambient environment of once living organisms, the sedimentary environment, and the diagenetic environment, and to recognize and treat the complexity of each. Each of these realms involves a variety of interface relations, climatic effects, interactions between organic and inorganic components, dispersal mechanisms, and gradients of several sorts that can be either clarifying to the perceptive or confusing to the unprepared.

Some fundamental problems that are interwoven with paleoecology include the origin of life, Precambrian evolution, biochemical and physiological evolution, the development of behavior, the nature and depth of sedimentary deposition, paleoclimatology, paleobiogeography, and the possible mechanisms and biogeochemical consequences of extinction. Summary discussion of these subjects underscores their complexity and their paleoecological significance.

SCOPE OF PALEOECOLOGY

TO ENVISAGE the life relationships and habitats of the past is the central aim of paleoecology. It shares, therefore, the unifying historical theme of geology, but like its immediate parent sciences, paleontology and ecology, it has its own distinctive problems and procedures. The necessarily imperfect approach to its basic ideal of determining and expressing the functional and energetic plexus of biotas and their environments through a continuum of time and space is made piecemeal and from many directions. In the sense that it deals with fossils, depends on their expert identification and interpretation, and contributes to better phylogenetic and evolutionary concepts, paleoecology is a part of paleontology. It is equally a complex interdisciplinary activity that seeks to understand and to interpret in mutual interrelation the life processes, sociology, behavior, habitat conditions, biogeography, and chronological development of prehistoric organisms, communities, and biotas. As such it draws also on the methods and materials of physiology,

[1] Publication authorized by the Director, U. S. Geological Survey.

Only the first half of this paper was presented at the Jubilee meeting of the Paleontological Society in St. Louis, 8 Nov. 1958. All of it, however, has profited from critical reading by W. A. Cobban, C. W. Merriam, V. E. McKelvey, Richard Scott, W. P. Woodring, and E. L. Yochelson, and from the meticulous editorial attention and typing of Doris Low.

[2] Geologist, U. S. Geological Survey, Washington 25, D. C.

geochemistry, sedimentology, oceanology, and climatology, and contributes to their paleo-equivalents.

The complexity of paleoecology and its tributary activities thus surpasses the scope of one man's competence; yet it can advance as a whole no faster than its parts. This calls, on the one hand, for generalists of broad enough reach or sufficient insight to formulate the problems, stimulate the essential specialists, and interpret the general results; on the other, for masters of specific fields of knowledge. Whether applied separately or together, on the same or on different problems, there is need in paleoecology for both types of endeavor.

Paleoecology, moreover, includes in its purview all types of environments and biotas. That I draw here for illustration primarily on the marine environment and the invertebrate biotas reflects my own limitations, not those of the subject.

RETROSPECT

The sources of ecology and paleoecology are reviewed in detail by Allee et al. (1949, p. 13–72), and at various places in the "Treatise on marine ecology and paleoecology" by Ladd et al. (1957). So we may concentrate here on present status and prospective future. Even the most hard-headed practitioner, however, should be aware of the basic historical development of his occupation; and it would ill befit a Jubilee celebration to forego the traditional bow of thanks to our principal intellectual ancestors, or the chastening reminder that some of our bright "modern" ideas can be found in the writings of people who preceded us by scores or hundreds of years.

Xenophanes, Xanthos, and Herodotus were the prophets but not the founders of paleocology, when, some 500 years before the Christian era, they recognized fossil seashells as evidence of former marine incursion in parts of Italy, Asia Minor, and Egypt. During most of the 25 centuries since these rude but significant beginnings, paleoecology made little further progress. Twenty of them had passed before Leonardo da Vinci (1452–1519) recognized the importance, and at least one means, of distinguishing between life associations and death assemblages in fossils. He wrote that paired fossil bivalves are evidence of live burial, separated shells proof of movement after death (da Vinci's notes, translation in Mather and Mason, 1939, p. 3–4)—a periodically rediscovered induction. And it was not until 1759 that the caustic but brilliant Jean Étienne Guettard wrote the earliest essentially paleoecologic paper on record, wherein he compared fossil associations with recent ones (Fenton and Fenton, 1952, p. 27–34). D'Orbigny, who contributed so much to all fields of paleontology, may have been the first publicly to recognize a vertical zonation in the sea, in 1820, and H. Milne Edwards and A. de Quatrefages introduced diving as a technique in ecological investigations about 1844 (J. W. Hedgpeth, *in* Ladd et al., 1957, v. 1, p. 3).

Prepared by these flirtations, the field was ripe for mastery when, in 1844, M. Edward Forbes securely established his parentage of marine ecology and paleoecology as distinct twin-disciplines with his "Report on the Mollusca and Radiata of the Aegean Sea." Forbes (1844, p. 172–179) delineated eight depth zones in the upper 230 fathoms of the Aegean Sea, discussed criteria for recognition of similar fossil records, and recognized that isothermal belts of latitude are equivalent to zones in depth. He emphasized the concept of maxima of development for species and genera in depth, space, and time, and stressed the sharpness of depth zonation among the Foraminifera. Then the treatise by Forbes and Godwin-Austen (1859) on "The natural history of the European Seas" elaborated the basis for later advances in marine ecology, with proper emphasis on its geological aspects. This was published just 100 years ago, in the same year as Darwin's "Origin of species" and the founding in France of the first marine science station at Concarneau—a great year for ecology and paleoecology!

Meanwhile from the wilderness of western New York, gangling young James Hall of Albany proclaimed (1843, especially p. 232–237) that we could read in the most ancient rocks of the region important physical characteristics and living conditions of former seas by means of sole markings, shell orientations, and sedimentary structures such as are now being widely rediscovered.

The first major work in American marine

ecology, with much of interest for paleoecology, is A. E. Verrill's "Report upon the invertebrate animals of Vineyard Sound etc." published in 1874 in the first annual report of the United States Fish Commission. Habitat notes in a still earlier book, C. B. Adams' 1852 "Catalogue of shells collected at Panama," provide the most comprehensive account yet available on the ecology of American tropical marine mollusks. Nonmarine ecology and paleoecology, of course, have had their parallel developments. By the very nature of their working materials and employment opportunities, however, authors of papers that deal with nonmarine paleoecology have tended to draw even more heavily than marine paleoecologists on functional deduction from morphology or taxonomic resemblance, with insufficient regard to other types of evidence.

Paleoecology nowadays is in a state of renewed ferment. After its slow initial development and turn-of-the-century doldrums it seems to be entering the steep phase of an exponential growth curve. Activity is on the upsurge in many lands and languages, but a large part of the basic substance of paleoecology is summarized in nine major English-language works:

1. *A. W. Grabau's "Principles of stratigraphy," 1913;* a comprehensive summation of most then known about the biologic interrelations and genesis of sedimentary deposits, especially marine.
2. *A. J. Lotka's "Elements of physical biology," 1925;* the classic work to date on energy systems in ecology.
3. *A. C. Seward's "Plant life through the ages," 1931;* a penetrating review of the distinctive fossil floras and their paleoecological implications and setting. An important supplement, with emphasis on the modern floras, is Stanley Cain's "Foundations of plant geography," 1944, especially p. 29–121.
4. The second revised and critically enlarged edition of *W. D. Matthew's "Climate and evolution," 1939;* the only extended summary dealing with the fundamentals of vertebrate paleoecology.
5. *"The oceans," by Sverdrup, Johnson, and Fleming, 1942;* still the basic treatise on oceanology, of which Ommanney's "The ocean" (1949) is a simplified condensed version.
6. *C. E. P. Brooks' "Climate through the ages," revised ed. 1949;* treats the dynamics of climate and ocean circulation and reviews selected geological problems in the light of generalizations recognized. Schwarzback's "Das Klima der Vorzeit" (1950) is a more recent account with a much more comprehensive synopsis and paleoclimatologic inference, but without so useful a summation of principles. Related ideas and data, and some significant elaborations of subjects treated by Brooks, are given in the volume "Climatic change" (1953), Harlow Shapley, editor.
7. *W. C. Allee et al., "Principles of animal ecology," 1949;* the basic current reference work for animal ecology in any language.
8. *G. E. Hutchinson's "A treatise on limnology, vol. 1—Geography, physics, and chemistry," 1957;* will be the basic reference work in limnology with publication of vol. 2, treating of biolimnology. Ruttner's "Fundamentals of limnology" (1953), a translation from the German, covers much of the ground briefly and very well.
9. The monumental two-volume *"Treatise on marine ecology and paleoecology,"* with sections by some 100 specialists from many lands under the chairmanship of *H. S. Ladd, 1957;* herein referred to as "The Treatise."

To round out his reading in the nonmarine field the prospective general paleoecologist will seek familiarity also, for *plant paleoecology* with works such as those of Bailey and Sinnott (1916), Reid and Chandler (1933), Berry (1945), Chaney (*e.g.* 1940, 1949), Axelrod (*e.g.* 1952, 1956, 1958), and Barghoorn (*e.g.* 1953); for *vertebrate paleoecology* with papers by Olson (*e.g.* 1948, 1952, 1957), Romer and Olson (1954), Romer (*e.g.* 1955, and books), Myers (1949), Simpson (*e.g.* 1953, and books), Shotwell (1955), and Mook (1916); for *nonmarine molluscan paleoecology* with studies such as those of Jekelius (1932), Wenz (1942–1946), Stevanović (1951), Yen (1947, 1951),

Alizadye (1954), and Taylor (1954); for *paleolimnology* especially the works of Gilbert (1890), Bradley (*e.g.* 1948), Brooks (1950), and Deevey (1953); for *paleoentomology* the recent paper by Palmer (1957) and references cited in a summary by Carpenter (1953); and for *salt marshes and tidal flats* the generally overlooked short classic by J. B. Knight (1934), and the papers of Rücklin (1954), van Straaten (1954), Solle (1956), van Straaten and Kuenen (1957, 1958), and other Dutch (*e.g.* Kuenen et al., 1950) and German (*e.g.* Reineck, 1956; Häntzschel, 1956) students of the classic Wadden- or Wattenseen.

PRINCIPLES AND PROCEDURES

GENERALITIES

Classical procedures in marine paleoecology were synthesized by Johannes Walther in 1893–1894. His basic plan was summarized in Vaughan's 1939 presidential address to the Geological Society of America (published 1940), which led to The Treatise on Marine Ecology and Paleoecology and indirectly to the representation of paleoecology on the present program. Ladd's section on "Paleoecological evidence" in The Treatise (Ladd et al., 1957, v. 2, p. 31–66) and recent reviews by George (1958b) and Ladd (1959) outline subsequent advances in the marine realm and underscore the limitations of usually available data. Terrestrial plant paleoecology was reviewed by Cain in 1944 (p. 29–121), but the most recent summary of vertebrate paleoecology is the 1939 edition of Matthew's classic "Climate and Evolution," and a general survey of terrestrial paleoecology is needed. Works by Hecker (1957), Ivanova (1958), and there cited indicate current activity and interest in the Soviet Union.

Despite much heartening progress paleoecology is still groping toward a coherent body of critical observations and specific principles by means of which the evidence can be winnowed and refined, its applicability established, and durable inference reached where data are adequate. Interpretation of existing and new records, meanwhile, depends largely on the application of two general unifying principles that apply throughout science and provide a common foundation for the experimental and the empirical disciplines: (1) the principle of parallel relationships, which says that parallel associations tend to behave in parallel ways, and (2) the principle of proportionate relationships, which says that intermediate things generally behave in intermediate ways and in proportion to their distance from the end points.

Paleo-ecosystems can be only roughly reconstructed, even for arrested paleoecological associations, such as the preserved sessile communities of organic reefs and bioherms (*e.g.* Lowenstam, *in* Ladd et al., 1957, v. 2, ch. 10). For the latter, one can observe the solid fraction of the community, deduce the population dynamics from growth curves and comparable measurements on death assemblages, suggest the nutrient or trophic relations from analogy with parallel modern assemblages, outline temporal and biogeographic distributions from field data and taxonomy, and even infer the physical and chemical properties of the ambient and sedimentary environments from geochemical and sedimentological data. Few published paleoecologic studies of other environments attempt, or should attempt under currently standard procedures, to suggest more than general habitat conditions. But humble recognition of these defects in our evidence and methods should not blind us to the tremendous advantages in paleoecology of the time dimension, and of the frequently far greater accessibility of the fossilized aquatic record over its modern counterparts. Defects inherent in the static nature of the paleoecological evidence with regard to the critical questions of immediate biological interaction and missing biotic components are the price paid for the chronological record and its commonly better fabric of space and depth.

Let us now briefly consider some currently available approaches to paleoecological inference. Against such a background, questions of limiting relations, salient problems, and future weaponry can be more meaningfully viewed.

PARALLEL ASSOCIATIONS

A common deductive principle in paleoecology is that of parallel associations, wherein a fossil assemblage and its enclosing sediments is compared with common or

widespread existing associations. Matching of various types of fossil and living reefs is a familiar application. An often cited parallelism is also found between the diatomaceous mudstones of the Monterey shale and equivalents of California and the anaerobic green diatomaceous muds of Southwest Africa (Walvis Bay) and the Gulf of California, all associated with catastrophic fish mortalities. From the principle of parallel relations, the details observed imply an origin for the Miocene deposits in cool, moderately deep, hypertrophic waters subject to episodically accelerated coastal upwelling and noxious plankton bloom; an environment that is consistent with paleontologic data indicating depths of deposition of 300 to 500 fathoms or more (Woodring, Bramlette, and Kew, 1946, p. 40). Conventional comparative paleobotany offers some of the most rewarding comparisons of this sort—for instance, environmentally adapted xerophytic or aquatic types of plant assemblages, or particularly well preserved climatic associations such as the thermally subtropical flora of the London clay (Brooks, 1949, p. 96; Reid and Chandler, 1933, p. 47–89).

GROSS FUNCTIONAL ANALOGY

Deductive extrapolation to the past from broadly restricted groups of living organisms or present ecological generalizations is a convergent form of paleoecological reasoning. Sharks and seals live in the sea, corals and dasycladacean algae flourish best in warm shallow water, charophytes live in fresh water, striated cobbles and surfaces suggest glaciation, mineral nutrients and autotrophic organisms are at the base of all food chains. The uncertainties of logical extension, however, in contrast to basic processes and quantitative relations, tend to increase exponentially with time and with decrease in the number of variables considered. Sharks and seals *can* live in fresh water, small reeflike buildups of ahermatypic corals and brachiopods *are* found in Scandinavian fjords and the deep Mediterranean, charophytes today *can* live in quite salty water and perhaps had still wider salinity tolerances in the Paleozoic, striated cobbles and surfaces *may be* produced by slides, mudflows, *nuées ardentes*, and suspension currents.

It is thermodynamically impossible, however, for an allotrophic fauna to survive without an associated autotrophic community, or for photosynthesis to occur without there being light, carbon dioxide, and oxygen. Although we have yet to see direct evidence of it, it is certain that the surface waters of the most ancient seas with animal life in the usual sense supported a population of photosynthesizing plankton. The porphyrins that occur in crude oils and bituminous shales from earliest Paleozoic onward (Abelson, 1959, p. 100, from Treibs) may be all that is left of these essential microorganisms.

ADAPTIVE CHARACTERISTICS

Morphological clues to specific habit, habitat, or physiology also provide sharp deductive tools in the hands of a competent specialist with a proper regard for the rule of exponential uncertainty. Living species that have sharply limited depth ranges in given areas (*e.g.* Le Danois, 1948, p. 228–280) presumably for the most part retained similar depth ranges under similar thermal zonation in the past. The method is exemplified by Woodring's illuminating study (1928) of a collection of Miocene mollusks from an area he had not previously seen in the field. By critical identification and meticulous analysis of available live records, he was able to show that the fossil assemblage from Bowden, Jamaica, was very probably deposited in mixed association along a steep slope that reached from a coastal shelf to water more than 100 fathoms deep. Even more refined analyses, based on similar data, but reinforced by richer analogy with modern faunas and a personal knowledge of field conditions, are given for a variety of Pleistocene marine environments in southern California by Woodring, Bramlette, and Kew (1946, p. 86–96).

Equally classic for botanical paleoecology is the study by Bailey and Sinnott (1916) in which they establish the broad relation between general climatic conditions and the dicotyledonous leaf margin. Indeed general clues to habitat are commonly suggested by the tendency of relatively unrelated organisms to develop similar adaptive characteristics under similar habitat conditions. Succulent spurges (Euphorbiaceae) are the ecologic counterparts of the new world cacti

in warm and dry old world habitats. Intertidal woody plants called mangroves belong to groups as distantly related as the Rhizophoraceae and the laurels. Planktonic organisms and windborne seeds specialize in light construction and filamentous appendages. Benthonic invertebrates with streamlined shapes and smooth exteriors are likely to be sediment burrowers or surf dwellers. Forbes (1844, p. 172–173) early called attention to the fact that bright colors and color patterns in the shells of marine mollusks imply depths less than 100 fathoms—ordinarily much less. And the fact that asymmetrical coloration is characteristically pale or absent on the side away from the light can be used to deduce living orientation and locomotor habits (*e.g.* Foerste, 1930).

Nor should we underrate the physical works of organisms. The striking similarity of certain feeding burrows of living nereid worms to furrows found by Seilacher in the Lower Cambrian of Pakistan (text-fig. 1) implies similar habit and habitat, whatever organism was responsible for the Cambrian ones. The crawl-tracks of olenellid trilobites from the same rocks suggest habits of feeding and motion similar to some living crabs. Different suites of feeding and searching tracks and burrows, both invertebrate and vertebrate, can be used to characterize different sedimentary environments.

GRADIENT RELATIONSHIPS

Statistical generalities that involve gradients of some sort allow us to apply the principle of proprotionate relations to the interpretation of ancient communities and sediments. The fact that decreasing salinity is accompanied by decrease in number of shelly species and in size and thickness of shell, for instance, was applied with conspicuous success by Goldring (1922) in her classic analysis of the Champlain Sea.

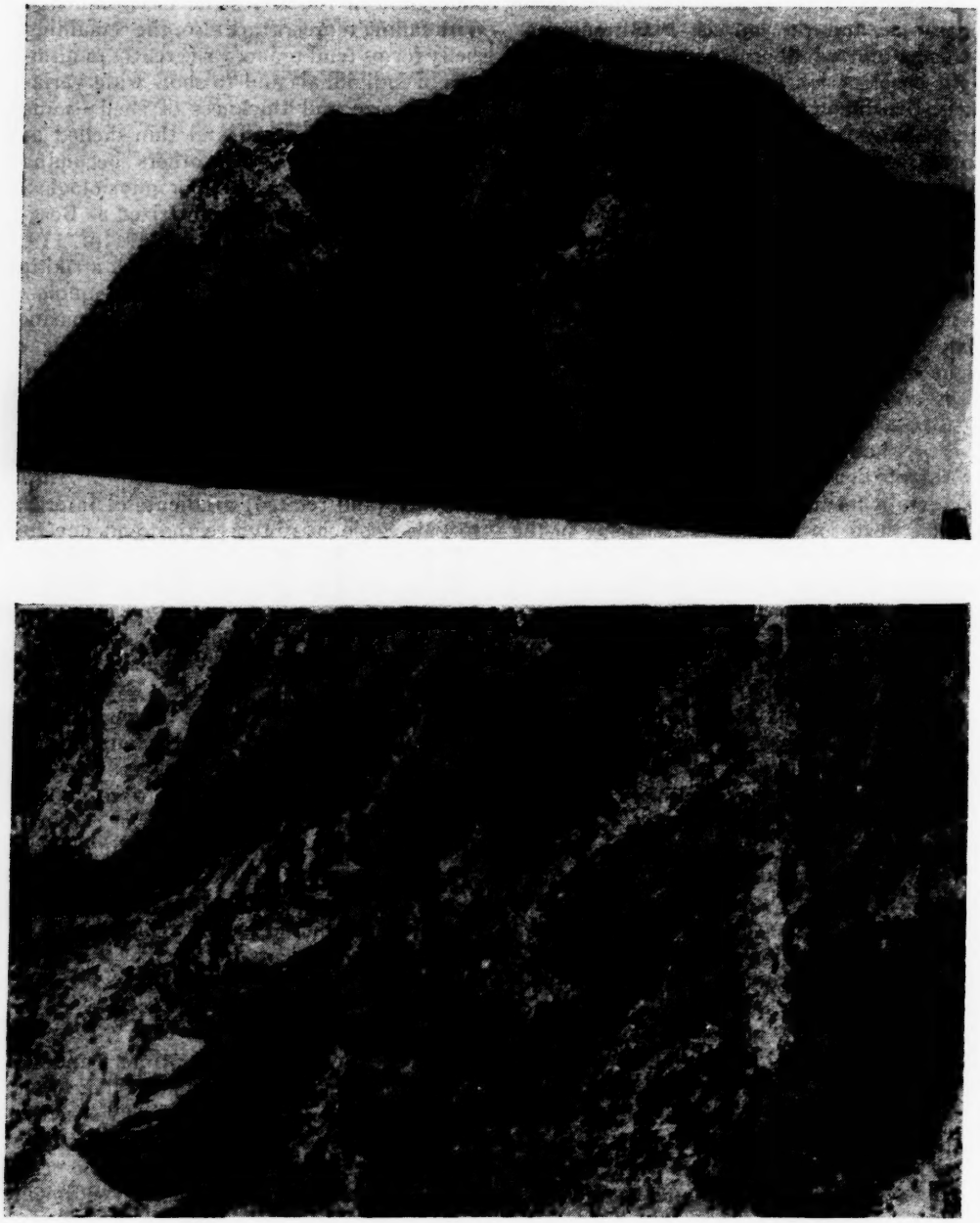
A similar decrease in number of species and higher categories occurs with decreasing temperature, although temperature changes in the marine environment are rarely so abrupt as salinity changes. Thus (Rukhin, 1957, p. 25) the Indo-Malayan marine fauna includes about 40,000 species, whereas the Mediterranean has only about one-sixth this number, and the Bering Straits have barely over one-third as many species as the Mediterranean (a far more drastic variation of both species and temperature is undergone in the terrestrial environment). With falling temperature also, the remaining shelly forms tend to increase greatly in numbers of individuals and to show wide variations in size and thickness of shell—some species becoming small and thin-shelled as in brackish waters, but others becoming robust and thick-shelled. For physiological and metabolic reasons summarized as Bergmann's rule (Allee et al., 1949, p. 119; Rukhin, 1957, p. 26–28); and with striking exceptions such as elephants and sequoias; warm-blooded animals, non-shelly marine invertebrates, and non-calcareous algae generally grow larger in colder environments, whereas the larger species of cold-blooded animals, shelled invertebrates, and land plants are generally found in mild climes.

Other (and related) gradients of interest to paleoecologists involve the tendency for the number of species in genera or larger groups to decrease away from optimum habitat conditions or away from presumed sites of origin or migration centers.

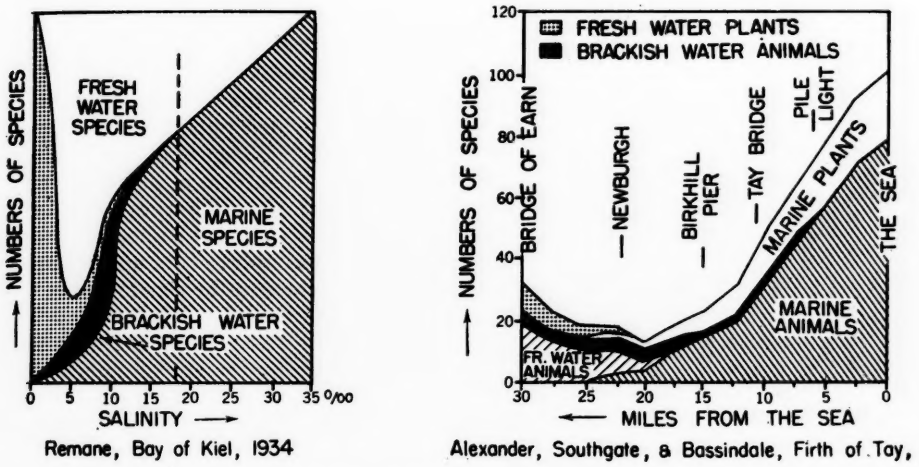
Gradient relationships, to be sure, should be interpreted with caution. Evidence of more than gradation should be sought, such as the habit of brackish water faunas to be characterized by fishes and crustaceans, which are protected from dilution of body fluids by osmosis. Assemblages of estuaries (text-fig. 2), inlets, and tidal flats in general, whether grading to fresh or hypersaline conditions, are characterized by marked variation of biotas in short distances and commonly by great numbers of a few especially adapted and euryhaline species.

GEOCHEMICAL EVIDENCE

Geochemical clues to the primary and diagenetic environment are now developing apace. Among many stimulating works that might be cited in illustration of this, that of Krumbein and Garrels (1952) on the origin and classification of the chemical sediments stands out for clarity, breadth, and usefulness to the paleoecologist. Another source-paper and critical review of penetrating significance for paleoecology is Krauskopf's "Sedimentary deposits of rare metals" (1955). Without attempting to review the field at large—and bearing in mind impor-



TEXT-FIG. *1*—Feeding burrows of living *Nereis diversicolor*, A, compared with structures made by unknown Early Cambrian organism from Pakistan, B (after Seilacher, 1957, pl. 23).

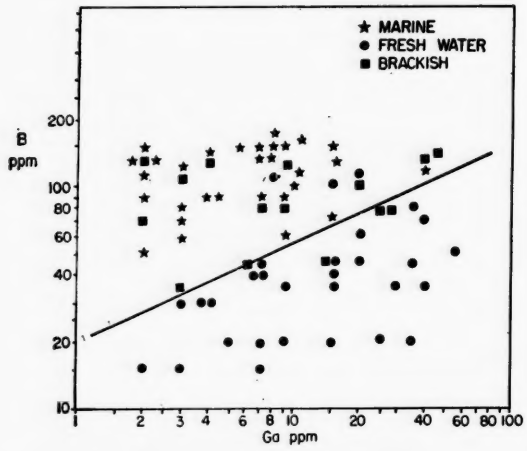


TEXT-FIG. *2*—Variation in estaurine biotas with changing salinity (after Hedgpeth, *in* Ladd et al., 1957, v. 1, p. 703).

tant distinctions of energy gradient, associations, and time—let us here merely note a few generalities that appear to have good inductive or experimental bases. For example, pyrite, galena, and other sulfides indicate markedly reducing conditions; glauconite symbolizes mild and commonly localized reducing conditions and slow sedimentation; ankerite and other carbonates require positive Eh (oxidation-reduction potential), and pH near 8 or higher to form, but can and do persist below the sediment-water interface at negative Eh and low pH; and siderite has intermediate requirements (Krumbein and Garrels, 1952; Emery and Rittenberg, 1952, p. 791–794; Garrels, 1954; Thompson, 1955; Cloud, 1955; ZoBell, 1946). Non-detrital silica and chamosite perhaps most generally imply a pH near or below neutrality, and a range of Eh from moderately negative to low positive, while the manganese and iron oxides favor a similar pH but higher Eh (Emery and Rittenberg, 1952, p. 796; Siever, 1957; Krumbein and Garrels, 1952). Evidence such as the foregoing has been used by James (1954) and Hough (1958), for instance, in reconstructing Precambrian environments.

The value of the ratio C^{12}/C^{13} has been brought to bear on the question of organic vs. inorganic origin of carbon, and the ratio O^{18}/O^{16} has provided a geologic thermometer to the sedimentary rocks (Ingerson, 1953, p. 321–327, 341–342; Lowenstam and Epstein, 1954; Rukhin, 1955, p. 29–31; Epstein, 1959, p. 228–230). The latter will help to elaborate climatic and depth zones and thermal history, or perhaps even to differentiate hydrothermal from diagenetic and primary dolomite, if and where dolomitization has not altered original isotopic composition. As for magnesium, invertebrates with calcareous hard parts that contain large proportions of magnesium are strictly marine, and the amount of magnesium they contain decreases with temperature and thus with increasing latitude and depth (Vinogradov, 1953, p. 571–572). Other geochemical data of possible bathymetric significance involve the ratio of niobium to tantalum, which varies with origin of sediments and seemingly is greatest in deep sea deposits (Rankama, 1947; 1948; p. 51–52).

The strontium content of calcium carbonate was one of the first geochemical clues used to suggest the specific salinity of the parent solution. Although we are not yet certain to what extent strontium (and barium) concentration found may be related to biological factors in shells (*e.g.* Thompson and Chow, 1955), to variations in the equilibrium state of dissolved calcium carbonate, or to expulsion to pore fluids during transformation from aragonite to calcite,



TEXT-FIG. 3—Boron/gallium-ratios of shales of Allegheny age in western Pennsylvania (after Degens, Williams, and Keith, 1957, fig. 11).

under some circumstances Sr/Ca gradients in preserved shell material apparently do run parallel to former salinity gradients (Turekian and Waagé, 1958).

Other clues to the salinity of ancient water bodies are suggested by the work of Degens, Williams, and Keith (1957, 1958), and the general field of the geochemical estimation of paleosalinity is summarized by Keith and Degens (1959), who consider strontium unpromising for this purpose. Numerous measurements by Degens and Keith of trace elements in Carboniferous shales typed as to environment on paleontological evidence by Williams indicate boron and lithium to be significantly more abundant in marine shales, gallium and chromium in fresh water shales (text-fig. 3). Since these variations are apparently independent of potassium and aluminum concentrations (Keith and Degens, 1959, p. 42, table 1) the method can be applied statistically to the interpretation of organically indeterminate field units. In a similar manner, the tendency of the heavy isotopes of carbon, oxygen, and hydrogen to be enriched in marine waters provides other genetic clues that can or might be applied to chemical sediments (or skeletal materials) formed in equilibrium with their source waters—for example, the enrichment of C^{13} in marine carbonates Keith & Degens, 1959, p. 54–57).

SEDIMENTOLOGICAL EVIDENCE

The physical evidence of the structure, texture, mineralogical composition, and paragenesis of the sediments themselves has long provided important, if commonly mistranslated, evidence to the paleoecologist and is the subject of an extensive published record. As with the procedures already discussed, it will suffice here to mention a few examples of its application.

Physical clues to the separation of waterborne from airborne sediments may be provided by the selective effects of wind and water on the movement of mineral grains of differing specific gravity. Thus Engelhardt (1940) showed that the radii of garnet and magnetite grains in windborne sands are smaller with respect to quartz than in waterborne sands. Debyser et al. (1955) and Bradley (1957) found lag-concentration of the larger heavy mineral grains in wind-winnowed French and Texas sands.

One of the most familiar and apparently best established inductive conclusions in paleoecology is that dolomite of diagenetic or primary origin (as opposed to hydrothermal or other late replacement dolomite) characteristically originates in or under near shore or shoal saline waters of restricted circulation and relatively elevated temperature. This is based on independently observed areal and paleoecologic relations of dolomite-limestone equivalents of many ages, in widely separated localities, by many geologists (*e.g.* Cloud and Barnes, 1948, p. 94; Fondeur et al., 1954; Lecompte, 1957, p. 1062). The presence of such dolomite facies is now widely regarded as presumptive evidence for origin beneath or in warm, shallow, sluggish, hypersaline water, or water of uncommonly high pH, ordinarily toward shore or shoals if the water body is large. Perhaps the seas at times of widespread dolomitization therefore were in general more alkaline or warmer than now.

Many other sedimentological clues to the physical environment are also arrived at or substantiated inductively. Thus, as will be enlarged on later, the likelihood of mass redeposition of sediments by means of slides, sediment-flows, suspensions, and turbidity currents is well demonstrated experimentally and by field evidence (*e.g.* Russell et al., 1951). Going beyond this, mechanical

considerations and measurements indicating essentially unidirectional currents over long distances imply (Kuenen, 1957, p. 232) that even the most gently sloping bottom needed to keep an essentially unconfined gravity flow in motion over such distances would necessarily carry it to appreciable depths. The conclusion does not follow that all mass-redeposited beds formed in deep water, but other inductive evidence of the habitual deposition of the flysch-facies sediments below wave base is found in the undisturbed, horizontally laminated, fine grained sediments which occur so commonly between thicker beds or zones of graywacke, arkose, and grit in such redeposited sequences.

LIVING FOSSILS

Evidence from "living fossils" ordinarily extends from the particular to the general, although the particular in such instances may be sadly circumscribed or the general grossly misleading. An example where such evidence seems to be meaningful is that of *Lingula*, a member of the infauna of impure sands, silts, and muds beneath shallow to intertidal and tropical to warm temperate waters, where it lodges securely by its contractable pedicle and feeds by filtering finely divided organic matter through its lophophore (*e.g.* Craig, 1952). It is consistent with the petrographic and paleogeographic evidence to conclude that the persistence and conservative evolution of this primitive brachiopod and its close living relatives reflects early achievement of a high degree of harmony with a persistent habitat type. On the other hand, despite their great significance in other respects, relicts from deep water such as the segmented mollusk *Neopilina* (Lemche, 1957), may reveal little or nothing of value about the ecology of their ancestors. They probably survive because they have taken refuge in an environment of low competitive stress. This, nevertheless, is a body of evidence that deserves more extensive study and evaluation of its paleoecological implications, from the marsupial holdovers of Australia, to such as *Gingko*, the living pleurotomarians, *Neotrigonia*, *Limulus*, the living mystacocarids and onychophorans, *Sphenodon*, *Latimeria*, and the several living representatives of the primitive ray-finned fishes.

LIMITING RELATIONS AND INTERACTIONS

Equally important to recognizing what conclusions may safely be embraced is to discern which are of doubtful virtue; for the pathway to durable paleoecologic deduction is beset with seductive oversimplifications, while the inherently complex is made more so by interaction between components. The problem can be sufficiently illustrated by brief glance at a few fundamental limiting factors.

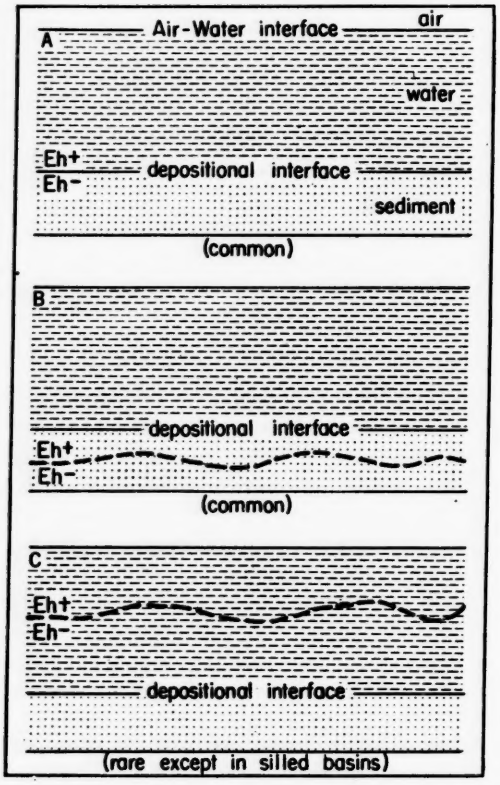
MOVEMENT OF MATERIALS

As has been appreciated by critical thinkers since the Renaissance, the first essential in dealing with fossil biotas is to know whether one deals with life associations or death assemblages, and the amount of movement after death. Clues that have proved useful in dealing with this problem include the extent of disarticulation and selective sorting of bivalved or segmented tests, comparison of sampled data with mortality and survivorship curves, mechanical sorting and orientation in general, wear and breakage, and position in the rock. Application of such evidences by Craig (1952, 1956) provides well-documented illustrations of fossil communities representing the preservable fauna of British Carboniferous shallow water to intertidal sediments.

The question of movement of sediments after initial depostion or diagenetic alteration is, of course, equally important in evaluating the bearing of mineralogical and geochemical data on paleo-environment. In this connection it should be emphasized that the use of wear and mixing of fossils, or other sedimentary particles, as a clue to amount of transport suffered is valid only if the transport was all tractional or saltative. There may be great transport in suspension currents, flowing sediment, or slides with little wear or mixing, and analysis of the sediments for evidence of such transport should be routine in paleoecological investigations.

INTERFACE RELATIONS

In dealing with the physical or chemical environment and its ecologic implications, interface relations also assume a place of primary but not widely enough recognized



TEXT-FIG. 4—Some characteristic relations between sediment-water depositional interface and redox (Eh) state (rearranged after Krumbein and Garrels, 1952, fig. 5).

importance. By interface relations I refer to the changes that take place across contacts or transitions such as those between water and air, water and sediment, sharply different layers of water or sediment, or organically enclosed spaces or pockets of one type of sediment and a surrounding sediment of another type (text-fig. 4). On the one hand, diffusion and mixing across the air-water interface has a greater effect on both sides than may be generally realized. Conversely, and more in need of emphasis paleoecologically, the change from water to sediment or between sediment layers may be almost as profound as that from air to water (or air to sediment). It is well known, of course, that stratification of the water in lakes or silled marine basins may result in sharp changes between water layers, occasionally leading to anaerobic conditions at depth and to elimination of benthic organisms altogether (although the upper waters may be teeming with organisms which may or may not accumulate and be preserved in the foul bottom deposits). It seems to be less generally appreciated by geologists, although now well known to oceanographers, that most normal marine water is reasonably well oxygenated to its greatest depths; while the oxygen content of interstitial waters below the depositional interface is a function of grain-size, bacterial flora, and interstitial circulation.

Because of greater total surface available for bacterial attachment, restricted interstitial circulation, and their commonly higher content of organic matter, the finer grained sediments tend to evolve more and lose less CO_2 than do coarser grained sediments, with consequently lowered pH and Eh. The multicellular infauna of such sediments consists of creatures that maintain contact with the oxygenated water above by means of appropriate breathing devices, or which can store oxygen between trips to the sediment-water interface. Organisms once permanently buried in such sediments are immune from the destructive biological effects of all except the relatively inactive anaerobic microorganisms, thereby providing the best of all preserving environments in the absence of destructive physicochemical effects.

Interstitial circulation and turnover may be vigorous, however, in clean sediments of sand size or larger which are exposed to current or wave action. The principal adaptation necessary for life within such well-oxygenated sediments is resistance to abrasion and ability to dig in or out when uncovered or too deeply buried, but good preservation requires rapid "permanent" burial.

Evidence of burrowing habit may provide clues to oxygen capacity of the sediment. Thus, the amphipod *Corophium* inhabits blind-ended burrows in clean well-oxygenated sands but makes U-shaped burrows in poorly oxygenated muddy sands. Even where the sediments are relatively coarse, moreover, change across the sediment-water interface may be abrupt in the absence of strong sediment motion or the presence of abundant fine-grained interstitial matter. Amphoras, columns, and other stony relics

recovered after long burial in relatively motionless Mediterranean sands are ordinarily well preserved to the extent they lay below the former sediment-water interface, whereas the parts above it are severely bored, weathered, and encrusted.

INTERACTION BETWEEN ORGANISMS AND SEDIMENTARY ENVIRONMENT

In fact, critical consideration of interactions between organic community and sedimentary environment or substrate is an essential part of any paleoecologic or ecologic study—as stressed in papers by Pérès and Picard (1955, 1958), Pérès (1957), Ginsburg and Lowenstam (1958), Cloud (1959, p. 387–400), and works cited by these authors. The physical and chemical characteristics of the substrate are changed by and commonly controlled by the organisms that live on, in, or near it. The organic community itself acquires new characteristics as a result of changes in structure and energy relations imposed by it upon the substrate. Boring organisms introduce oxygen to the sediments and may break them up, reorganize them into fecal pellets, or change their structure in other ways, preparing the original environment for new inhabitants and even modifying themselves in the process. Microorganisms profoundly affect the chemistry of the interstitial waters, introduce new physical processes, bring about rearrangements of the sediments, and prepare them for, or exclude, other inhabitants. Fish and vagrant epifauna also disturb and reorient the sediments, while sessile epifauna and settling plankton further modify the sequence. Organisms with hard parts supply sedimentary particles or biogenic buildups in the form of skeletal material, and reef-building communities in particular exercise far reaching influence on both sedimentary regimen and physical and chemical properties of the water itself. Sediment-binding and rock-disintegrating algae not only alter the substrate physically and affect its chemical composition and that of the waters in contact with it; they also prepare a base for initiation of marine angiosperm meadows, which, in turn, retard water movement, filter and entrap additional sediment, and lead to sedimentary buildup above surrounding levels. Even gravel and coarse sand may be formed by breakdown in place of some types of hard bottom by relatively subtle biologic processes (Pérès and Picard, 1955, p. 24). The general interactions outlined, of course, have their terrestrial counterparts, as expressed in the concept of climax and the factors that produce it or reverse climactic trends (e.g. Clements & Shelford, 1939, p. 229–250,294,313).

The net product, finally, of such organic activities and interactions within, on, and above a particular substratal layer with given initial physical, chemical, and biological characteristics varies with subsequent history and conditions and time of burial. The resultant biologic-sedimentologic-diagenetic plexus can only be unraveled on the basis of familiarity with existing environments and processes and the significant macro- and micro-facies characteristics of the rock and its organic components. Like a good forester the paleoecologist must know the trees without losing sight of the wood!

REVERSE GRADATIONS

In dealing with gradations of various sorts, reversal of the usual sense can be either confusing or helpful, depending on whether it is detected and interpreted in context or not. The general rule that clastic sediments grade from coarser to finer offshore is a deeply ingrained dogma, yet the reverse is true of many broad aggradational areas between tides where onshore tidal currents are strong, principal seaward movement of new sediment is concentrated in few outlets, and local fresh water inflow is weak. The tidal flats behind the Frisian Islands of northwestern Germany and Holland (Koning, *in* Kuenen et al., 1950; van Straaten and Kuenen, 1957, 1958), the Bay of Mont St. Michel and other tidal inlets around Brittany (Bourcart, 1957, p. 331–332), and Sagadahoc Bay on the Coast of Maine (Bradley, *in* Ladd et al., 1957, v. 2, p. 541–681) exemplify the conditions of primary movement of sediment onshore and grain size increase offshore. Only appropriately timed subsidence of areas the size of the first or second named is neeeded to produce extensive integrading wedges of such deposits.

Reverse graded bedding is also a rare but

real feature; it perhaps most commonly reflects the frictional segregation upward of larger particles in flowing, shifting, or vibrating masses of sediment in contact with a fixed substrate.

UNIVERSAL FORCES

To turn to quite another aspect of paleoecology which displays important limiting relations, each local environment is but a fragment of a regional and ultimately of a global environment whose characteristics at a particular time depend on the interplay of universal forces not ordinarily considered in paleoecologic reconstruction. Progress in paleoclimatology and paleobiogeography, for instance, calls for appreciation of latitudinal variations in wind fields, the effect of wind fields and of land masses and their orientation on ocean currents and climate, and the physiology and mechanisms of organic dispersal. Perhaps, for instance, some of the lithic and faunal facies differences in the Western Interior Cretaceous during time of north to south marine connections were related to obliquely impinging clockwise gyrals produced by the Coriolis effect of opposing water masses of southeasterly and northwesterly origin. Assuming marine connections to the southeast, and no drastic latitudinal change, the major non-gravitational feature of Permian Basin circulation in west Texas and adjacent areas was necessarily a clockwise gyral.

PROSPECT AND PROBLEMS

So much for procedures and limiting relations. Now what of the future? Some of the most obdurate strongholds of ignorance in geology and paleontology await new or renewed assault by paleoecological methods. Some of the most fruitful realms of knowledge await application to paleoecological problems. Some of the basic aims of paleoecology will remain unachievable without the aid of our sister sciences.

These assertions deserve to be illustrated, and, possibly at risk of seeming to overextend the subject, I find it the least dull to illustrate them by brief review of salient problems having a paleoecological bearing. The examples chosen, some of which were skirted in the preceding pages, are:

1. The origin of life and Precambrian evolution
2. Biochemical and physiological evolution
3. Prehistoric behavior patterns
4. Nature of sedimentary processes
5. Relief of ancient seas and lands
6. Paleoclimatology
7. Paleobiogeography and biotic dispersal
8. Possible causes of extinction, and their geochemical consequences.

ORIGIN OF LIFE AND PRECAMBRIAN EVOLUTION

The origin of earthly life was the first great paleoecological and biogeochemical event on our planet. No other living thing that has ever inhabited the earth can possibly have been so completely conditioned by its physical and physico-chemical environment as the first to carry on vital processes, however simple they were. Magnificent summaries of the problem by Pirie (1954) Barghoorn (*in* Ladd et al., 1957, v. 2, p. 75–85), and Haldane (1957), however, leave little for the present paper to add except the conviction that the time is ripe for supplementation of imaginative inference by vigorous scientific inquiry.

Such inquiry should seek not only to test the corollary requirements of existing hypotheses for the origin of the energy-capturing organic system which we call life, but to delimit more narrowly the probable paleoecological circumstances of the major achievements of Precambrian evolution. We need to know much more about the composition of the early atmosphere, hydrosphere, and crust; the syntheses of metastable molecules which could build subvital units and whose breakdown could provide an energy source for early life in the absence of oxygen or a mechanism for conversion of radiant energy; the possibility of substituting chelated metal ions for enzymatic catalyzers (Haldane, 1957). Assuming that life originated in a broth or concentrated matrix of previously non-living organic molecules as a result of some chance linkage or surge of energy, time required for buildup of a suitable molecular concentrate and its presumed subsequent consumption by the almost necessarily heterotrophic first organisms implies both that the successful first

event was unique and that its success was dependent on the early evolution of autotrophic forms of life. Recognition of the oldest autotrophic organisms or their paleoecological consequences would provide a point of depature for more pertinent evaluations of the related physical environment.

Other great steps in Precambrian evolution and paleoecology include the origin of photosynthesizing organisms and the creation of an oxygenous atmosphere; the development, probably, of the nucleated cell and chromosomes, and of sexual reproduction, whereby the gene pool could be varied and transmitted to different descendants; diversification into plants and animals; and, finally, the origin of multicellular animal life—the last event perhaps marking or barely preceding the beginning of the Cambrian (Cloud, 1948, p. 346–348). Only three more really major organic achievements occurred, the establishment first of terrestrial plants and then of animals, and the evolution of the central nervous system. Organic evolution as generally considered, with all its intrinsic interest and its significance for paleoecology, is to a large degree merely elaboration of events whose history must be sought within the Precambrian by geochemical and sedimentological techniques (*e.g.*, Thode et al., 1953) and by ceaseless and skillfully varied search for organic remains in the less metamorphosed fine-grained and carbonaceous sediments—especially the cherts, the algal limestones, and the shales.

BIOCHEMICAL AND PHYSIOLOGICAL EVOLUTION

Closely allied to the question of life origins, and with greater immediate significance for paleoecology, is the problem of biochemical and physiological evolution. Indeed behavior, morphology, and degree of reciprocity of organism with environment is fundamentally interrelated with and dependent on biochemistry and physiology. The nature of the task and the prospects of further progress are outlined in papers by Woodring (1954) and Abelson (1959, and *in* Ladd et al., 1957, v. 2, p. 87–92), and in references there cited. Abelson's searching inquiries on the paleobiochemistry of the amino acids tell us (*op. cit.*, p. 83), among other things, that no less than eight amino acids are preserved in chert of the Precambrian Gunflint iron-formation, thus supporting its partially or largely organic origin and indicating an advanced biochemical evolution in early and simple forms of life. Although reservation about the meaning of this result has wisely been expressed by Abelson himself, the work of Wetzel (1933) and Deflandre (*e.g.*, 1936, p. 13), illustrating essentially hermetic preservation of organisms in Cretaceous cherts, strengthens the probability that the large variety and volume of amino acids in the Precambrian chert is real. Amino acids of any great age, however, have so far proved to be the thermally more stable types (Abelson, 1959, p. 88,91,95), so they provide more information on the post-depositional history of the sediments than they do on the details of biochemical evolution.

Problems on which suitable biochemical methods might cast light, however, do come to mind. The detection of particular substances could illuminate the question of phylogenetic affinities and habitat of problematical groups such as the graptolites, conodonts, and early fishes. If the certain presence of the relatively unstable arginine could be established in graptolites or conodonts, this would support affinity to the chordata and, to some degree, perhaps, a different mode of life than if they were invertebrates; whereas if trimethylamine or an identifiable derivative could be found in the early fishes it would imply a marine habitat. This approach, to be sure, is beset with difficulties involving applicable methods, sites of biochemical concentration, stability and preservation, and contamination; but worthwhile achievements are rarely easy, and the progress already achieved would have seemed technologically improbable only a few decades ago.

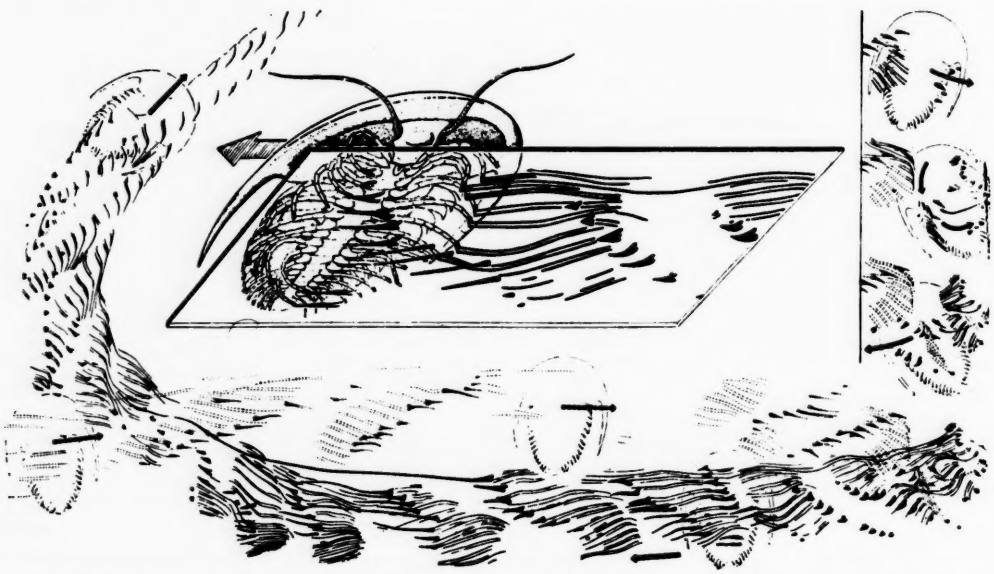
PREHISTORIC BEHAVIOR PATTERNS

The behavior of organisms and the evolution of behavior is in large degree a paleoecological problem, and one in which gross morphology, evidence of muscle arrangement, psychological probability, and paleoneurology can play important parts (Roe and Simpson, editors, 1958; Edinger, 1956). A large arsenal of weapons for the attack

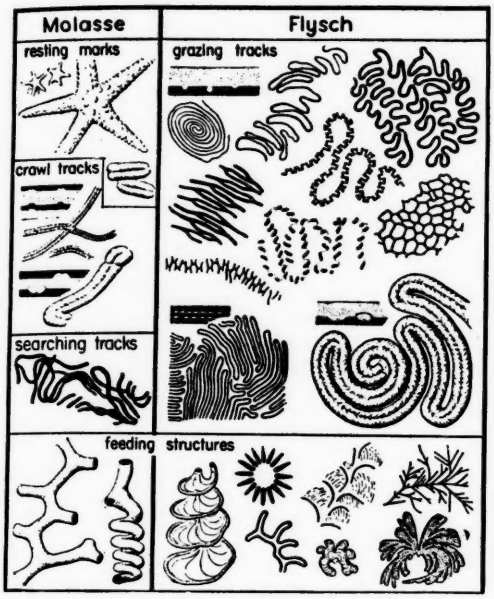
on the more purely resultant aspects of this problem is already available in the vast and largely Germanic bibliography on *Lebensspüren*, or life traces, for which no wholly satisfactory English or Latin term is in use. The classic early work was that of Fuchs (1895), and the basic current reference works are those of Abel (1935) and Lessertisseur (1955). Seilacher's recent summaries (1953, 1954) provide excellent condensations and bibliographies of this field, which its devotees call palichnology. Instead of recognizing that these *Lebensspüren* can commonly tell us far more about the tactile and feeding habits of the former living animal than its actual remains, however, American invertebrate paleontologists generally ignore them. Aside from the vertebrate paleontologists, who do much with footprints and trackways (*e.g.* Peabody, 1948), virtually the only substantial American contributions to the field so far have been those of the Fentons (1934, 1937), Brown and Vokes (1944), Howell (*e.g.*, 1945, and, with Hutchinson, 1958), Flower (1955), and Caster (*in* Ladd et al., 1957, v. 2, p. 1025–1032 and references there cited on p. 1030).

A splendid example of what can be done with past functional reactions and the evolution of behavior by means of these "trace fossils" is provided by Seilacher's studies (*in* Schindewolf and Seilacher, 1954, p. 86–116) of the living habits of certain Early Cambrian trilobites as reflected by their various trackways and markings. Not only did his Salt Range olenellids tiptoe along the bottom, they also skittered directly or obliquely to right or left, occasionally losing contact with the bottom as they planed sideways into slight currents, and probably grovelling into it for food. Their optional sidewise motion is implied by laterally successive similar arrays of paired tracks such as would be made by dragging a set of size-graded biramous appendages, matched by sets of blunter tracks that are mostly bifid at one end only and presumably were made by digging in of the propelling set of appendages (text-fig. 5). An equally interesting example of the interpretations obtainable from the works of organisms is the demonstration by Romer and Olson (1954) that estivation as an adaptation to intervals of desiccation was already established among Permian lungfish.

Even where we do not have existing counterparts of such *Lebensspüren* and cannot identify their makers, we can inductively learn much from their relations to one an-



TEXT-FIG. 5—Crawl-tracks of an olenellid trilobite as sketched from a slab of Lower Cambrian calcareous siltstone from Pakistan (after Seilacher, *in* Schindewolf and Seilacher, 1955, p. 350, fig. 3).



TEXT-FIG. 6—Types of *Lebensspüren* and their characteristic facies associations in Europe (after Seilacher, 1954, fig. 2).

other, to sedimentary facies, and to previously existing sole markings and physical structures in their enclosing sediments. Feeding patterns and burrows, for instance, can be differentiated from searching tracks and resting marks (text-fig. 6). Markings made between layers of sediment can also be told from those made at the sediment-water interface; they prove to be the dominant *Lebensspüren* in many deposits, and to reflect changes in grain size and presumably in oxidation-reduction potential at boundaries between sediment layers. Radiating dendroid markings once thought to be algae (*Chondrites, Lophoctenium*) can be recognized as the feeding burrows of unknown soft-bodied animals by the fact that the individual tunnelways of a given composite structure abut but do not overlap (the phenomenon of phobotaxis: Richter, 1931; Simpson, 1955). Burrows made by arthropods commonly display paired scratch marks on their walls.

Paleoneurology, as Edinger (1956) stresses, can provide as much insight to habit as to evolution and affinity. Distinctive dorsal protuberances of the olfactory lobes of upper Eocene but not older canids probably date the evolution of the olfactory tracking habit; and similar protuberances are found in the ordinally unrelated aardvark (*Orycteropus*) and the feloid *Hyaena*, who find their food in similar ways (*op. cit.*, p. 11–12).

Paleoecologists of the future should also pay a great deal more attention to symbiotic relations and associations of all sorts that will help in the reconstruction of food chains and analysis of interdependence, competition, and speciation pressures in fossil communities. Evidence is needed such as the record by MacGinitie and MacGinitie (1949, p. 94) of a commensal crab (*Scleroplax*) from a Pliocene echiuroid burrow in California. Pioneer works in this field are Clarke's 1921 bulletin on "Organic dependence and disease," illustrated in part with stereophotographs, and Moodie's 1923 compendium on "Paleopathology," and largest of many works by Moodie on pathology and symbiosis in the fossil record. Prime examples of commensal associations from early Paleozoic onward are preserved among reef organisms, annelids, and echinoderms, and the question of "Evolution and habit among the Echinoidea" is the subject of a premonitory paper by Hawkins (1943).

NATURE OF SEDIMENTARY PROCESSES

Since paleoecology is concerned with interrelations between organism and environment, and inasmuch as the entombing sediments are the only accessory evidence as to the nature of that environment, the paleoecologist is profoundly concerned with sedimentary and diagenetic processes. According to the principle of uniformitarianism, also, the study of present processes is the proper approach to the interpretation of past events, and much that is constructive has been done along these lines. It is doubtful, nevertheless, if any other great liberating concept in the history of science has received so much lip service in comparison to its application, and it particularly deserves to be stressed with regard to sedimentary processes that there is nothing in the principle of uniformitarianism requiring catastrophic events either to be considered as freakish interruptions in a "normal" course of gradual change or limited in variety.

To be sure, far and rapid transport of

sediments by suspension currents has long been suspected (*e.g.* Bramlette and Bradley, *in* Bradley et al., 1942, p. 16) and is now so generally recognized (*e.g.* Russell et al., 1951) that the concept is in danger of indiscriminate application. Yet other forms of mass-transport of sediment (*e.g.* Terzaghi, 1956) are not ordinarily invoked, and normal sedimentary processes are probably most generally thought of as essentially continuous downslope tractional and saltative movement to a permanent resting place below wave base or beneath younger sediments on a subsiding base. The physical and chemical nature, stability, and history of the biological substrate or enclosing sedimentary medium needs now to be considered more critically in terms of primary origin (not to mention the reciprocal sedimentary and diagenetic changes undergone as a result of organic processes).

Virtually all sediments except those of chemical origin, and they commonly, are redeposited in one way or another before finally entering the "permanent" diagenetic environment. Clastic or volcanic particles may be moved many times by wind, flowing water, or mass-wasting before they reach the sea or other large water body, and thereafter they are equally subject to repeated particulate or mass-redeposition until carried beyond even the most gentle slopes and buried out of reach of sea-floor currents, burrowing organisms, or the force of gravity.

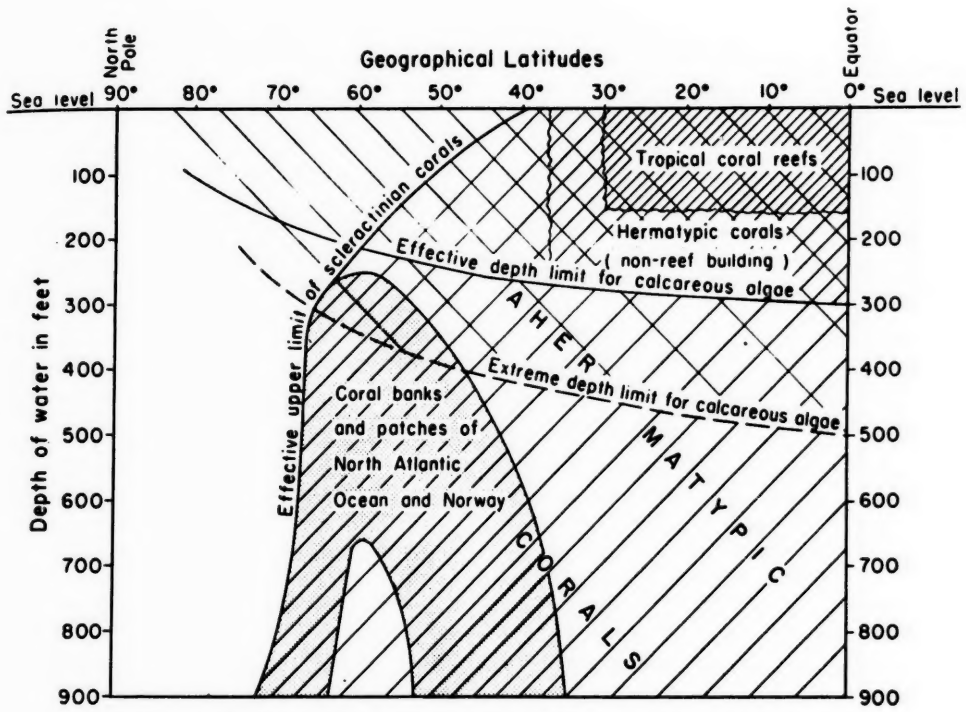
The frequent repetitive occurrence of sharply defined individual beds of relatively coarse clastics intercalated with and at many places greatly outbulking fine-grained thinly laminated sediments over very wide areas assuredly demands recurrent transportation mechanisms of great force, effective over long distances. From the available facts and the principle of uniformitarianism, it seems certain that these mechanisms involve sediment-flows, slides, and suspension currents of various sorts, including turbidity currents. Indeed, it is possible that the final movement of the great bulk of coarse basinal clastics in the geologic column was by some form of gravitational mass-movement. This, of course, needs further analysis, particularly as regards the clastic carbonate rocks. Also, pelagic sediments of a cosmic, organic, chemical, semi-colloidal, or mixed nature cover large areas of the present sea bottom and represent a far more continuous form of activity than does mass-redeposition—even though such deposits may not bulk large in the available geologic record.

Analysis of redeposited beds, and of the nature and orientation of sedimentary structures and external markings of all beds can tell the paleoecologist much about the nature, direction of flow, and even the velocity of the transporting current, sediment-flow, or slide. Spindle-shaped sole markings (flute marks, or "turboglyphs"), the bottom tracks of vortexes, indicate the passage along the sea floor of a true turbidity current, and point in the direction from which the current came. Composite bedding, produced as a result of pulsating but essentially continuous mass movement implies the action of a strong bottom current or sediment flow. Systematic orientation of crossbedding or imbrication of pebbles indicates unidirectional tractional current movement and signifies its direction and sense. The origin and contemporaneous deformation or truncation of ripple marks has definable relations to current velocity (Gilbert, 1914, p. 30–33), and it is even conceivable that the orientation and scale of current bedding can be numerically related to such a parameter as the Froude number of the current and thereby its velocity (*cf.* Brush, 1958). Additional clues to direction and nature of sedimentary transport are given by Kuenen (1957), van Straaten (1951), and others therein cited. Of course, different or intergrading modes of transport may be responsible for different parts of a single sedimentary unit.

George (1957) has written a more extended critical summation of recent work on sedimentary processes and structures, with due words of caution for the over-eager Papers by Sujkowski (1958), ZoBell (1946), Emery and Rittenberg (1952), and by Krumbein and Garrels (1953) provide a basic reference frame for further reading on diagenesis.

RELIEF OF ANCIENT SEAS AND LANDS

Biological criteria of obvious sorts (text-fig. 7) are overwhelmingly the most useful in



TEXT-FIG. 7—Broadly generalized depth ranges of existing corals and calcareous algae (after Teichert, 1958, fig. 3).

estimating depths of Cenozoic water bodies or heights of Tertiary lands, but the principle of exponential reservation becomes important as we move further back into the past. Woodring (1928), among others, has illustrated the application of specific organisms to the estimation of depth in Tertiary seas, and Gignoux (*in* Moret, 1952, fig. 22) used the frequency distribution of sponge genera to suggest a depth of deposition of 300 to 400 meters for the Upper Cretaceous of Germany. Algae, especially the dasycladacean algae, are highly significant for estimation of depth (Cloud, 1952, p. 2134); and depth estimates based on Foraminifera and corals are legion, especially in the Mesozoic. A few specific organisms, for instance *Lingula* (Craig, 1952), are even considered useful depth indicators far into the Paleozoic. Before the Mesozoic, nevertheless, about all we know with certainty is that plants required light, and that aquatic ones therefore lived within the photic zone.

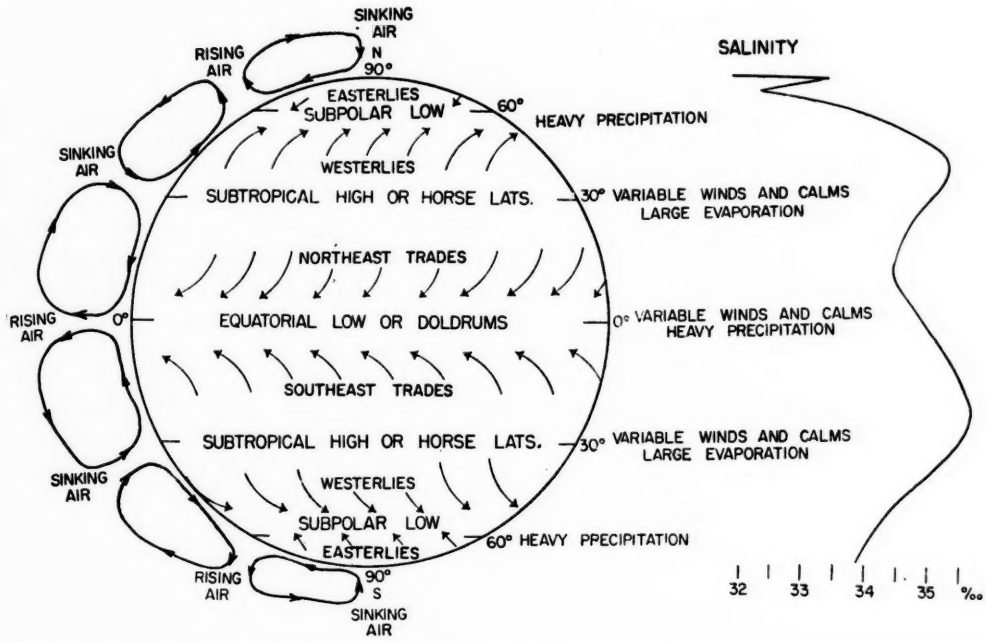
Some physical clues, however, have been suggested as indicative of broad limits for depths and heights, and more need to be developed. In theory, sediments could ordinarily obtain and retain a primary horizontal lamination only where protected from disturbance, as beneath wave base, through binding by successive slime films in an area of weak wave action such as a wide tidal flat or a swamp, or in settling basins of some sort (Seibold, 1958). However, chemical sediments commonly, and clastic sediments in a suitable diagenetic environment, may become secondarily laminated or banded as a result of diffusion or unmixing processes (*e.g.* Sujkowski, 1958, p. 2709–2710, 2714–2715). A consistent orientation of cross lamination implies deposition below wave base under the influence of unidirectional gravity currents; random orientation of cross bedding implies random wave and current action and thus shallow water. Polygonal desiccation cracks, rain drop or hail imprints, and the marks of ice-crystals as evidence of subaerial exposure of water-laid sediments are almost too obvious to mention, except to caution against confusing

them with cracks and pits made by the escape of gas or water from sediments, or with organic markings.

Elevated or rising lands, and depressed or subsiding basins are almost universally considered to be demonstrated by the introduction of large volumes of coarse clastics into a sedimentary sequence that previously lacked them. As mentioned earlier, it bears on this that many observations of sole markings and sedimentary structures in clastic beds by Kuenen and others (*e.g.* Kuenen, 1957, p. 232) have shown persistence of nearly uniform current direction in long sedimentary belts and through large thicknesses of sediment, apparently demanding strong and persistent currents that flowed for great distances in elongated sedimentary troughs with ample sedimentary supply and unstable slopes. Considering even the very gentle slopes (*e.g.* Arkanguelsky, 1930, p. 80) on which flow or gliding displacement of sediments can take place, one may logically reason that distances of hundreds of kilometers mean depths of kilometers. In fact, Ksiazkiewicz (1958) has traced unidirectional current movement for over 100 km. in the Inoceramian beds of the Carpathian flysch, while Kuenen and Sanders (1956, p. 669) find evidence that turbidity currents extend 40 km. from their inferred source in the Carboniferous of Germany. It also turns out, from studies by Seilacher and others (*e.g.* Seilacher, 1954), that the *Lebensspüren* of the Alpine flysch and similar sequences of interbedded laminated shales and redeposited coarse clastics are characterized by great regularity of pattern which is rarely, if ever, so well developed in deposits of known shallow water origin (fig. 6).

The weight of inductive logic seems then to support the broad interpretation that the natural depositional sites of the great sequences of flysch-facies sediments are geologically rapidly subsiding and generally deep, elongate, and perhaps pitching depressions adjacent to tectonic lands. It should not be necessary to emphasize that such receptacles were not everywhere deep and that no special depth is required for the initiation of gravity mass movement. Increasing depth, however, presumably would improve chances of the preservation of the distinctive sediments, where subsidence and burial is not rapid, as well as the formation and preservation of horizontally laminated interbeds—some of which in the flysch-facies are found to be rick in pelagic microorganisms. And, finally, since initial mass movement of the sand-sized and finer sediments not due to flood regime implies the preceding temporary buildup of an unstable mass of sediment in an aqueous environment, the general conditions favoring evolution and persistence of the flysch-facies sediments also are consistent with terminal deposition mainly at depths well below wave base.

Emerged deposits of deep bathyal or truly abyssal origin have never been established to the general satisfaction of geologists, although they probably exist and might be more common than we think. Evidence advanced in favor of deposition at depth includes abundance of manganese nodules and phosphate, fish teeth with dissolved dentine, radiolarites or radiolarian-bearing chert and siliceous mudstone, benthonic fossils of supposed deep sea habitat, and red clay. Based on such evidence, the strata most widely regarded as of possible deep sea origin are those of the middle Eocene to Oligocene Oceanic series of Barbados (Senn, 1940, p. 1577–1588) and the Devonian to Triassic Danau beds of Borneo (van Bemmelen, 1949, p. 63–64). Indeed, the case for deposition of these beds in a substantially open-sea environment and at depths well below wave base, as in the case of the flysch-facies deposits in general, is certainly as well established as the shallow water origin of many other sediments. The crying need is for more quantitative criteria—whether physical, geochemical, or biological doesn't matter. But all should be refined and the results of the three types of data should be consistent in any given instance. Among other prospects it might be rewarding to look further into the suggestion of Rankama (1948) that niobium /tantalum ratios attain maximum values in the deep-sea sediments. Critical comparative study is also called for of the characteristics of sedimentary rocks in areas where there is possibility of reconstructing a reasonably objective paleobathymetry, as in the now well-known Ventura Basin of Cali-



TEXT-FIG. 8—Schematic wind-system for a hypothetical water-covered earth, and mean annual salinities of present surface ocean waters (after Fleming, *in* Ladd et al., 1957, v. 1, p. 90–91).

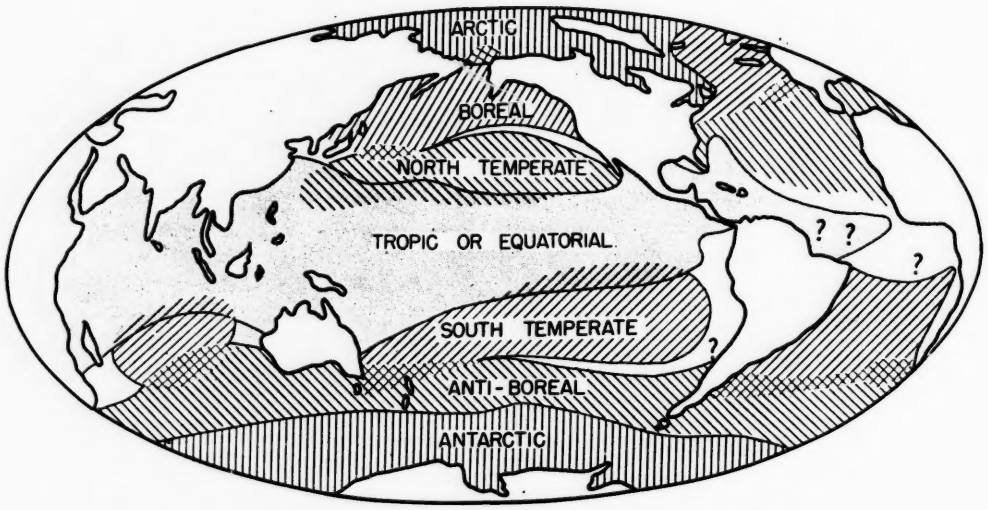
fornia or other areas where the endemic fossils indicate a wide range of depth, or as has been suggested for the Permian Basin and Guadalupe Mountains of west Texas and New Mexico (King, 1948, p. 85; Adams and Frenzel, 1950, p. 297–298,307; Newell et al., 1953, p. 189–191).

PALEOCLIMATOLOGY

Climate is an ecological factor which depends on the circulation of the atmosphere (text-fig. 8) and the sea, the distribution of land and water, the position and inclination of the earth's rotational axis, the composition of the atmosphere, the path of the earth about the sun, and on strictly solar manifestations. Landsberg (1958) has reviewed recent climatic trends, and Brooks (1949), Schwarzbach (1950), and Lasareff (1929) have suggested how they might be projected into the past. Shapley et al. (1953) have summarized possible causes, effects, and evidences of climatic change, and Rukhin (1955) has provided an excellent condensation of paleoclimatic indicators and manifestations. The way to more rigorous analysis of paleooceanographic data and reproduction of ancient marine currents has been outlined by Stommel (1957) and von Arx (1957).

From these works we know that the rotation of the earth, the position of the polar axis, and the thermal variations of the atmosphere determine the major wind fields, and that wind patterns and size and orientation of land masses are the principal determinants of ocean currents. If, now, we add the Coriolis deflection (right in the northern hemisphere, left in the southern hemisphere), the monsoon effect of onshore summer and offshore winter winds from large land masses, the thermal influence on oceanic circulation, and the general relief and land connections, we have named the paleoclimatic and paleocurrent factors that can profitably be considered on a broad scale, and which give rise to the broad biogeographical subdivisions of land and sea (text-fig. 9).

Employing a rotating tank apparatus similar to that of von Arx (1957) to create patterns of oceanic circulation for various

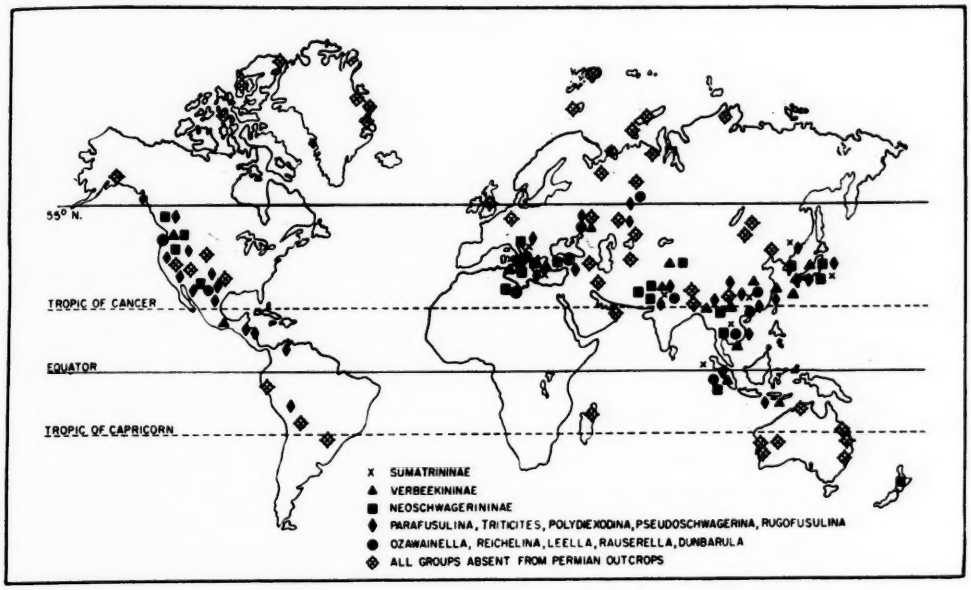


TEXT-FIG. 9—Worldwide biogeographical belts as defined by marine plankton (after Hedgpeth, *in* Ladd et al., 1957, v. 1, p. 367).

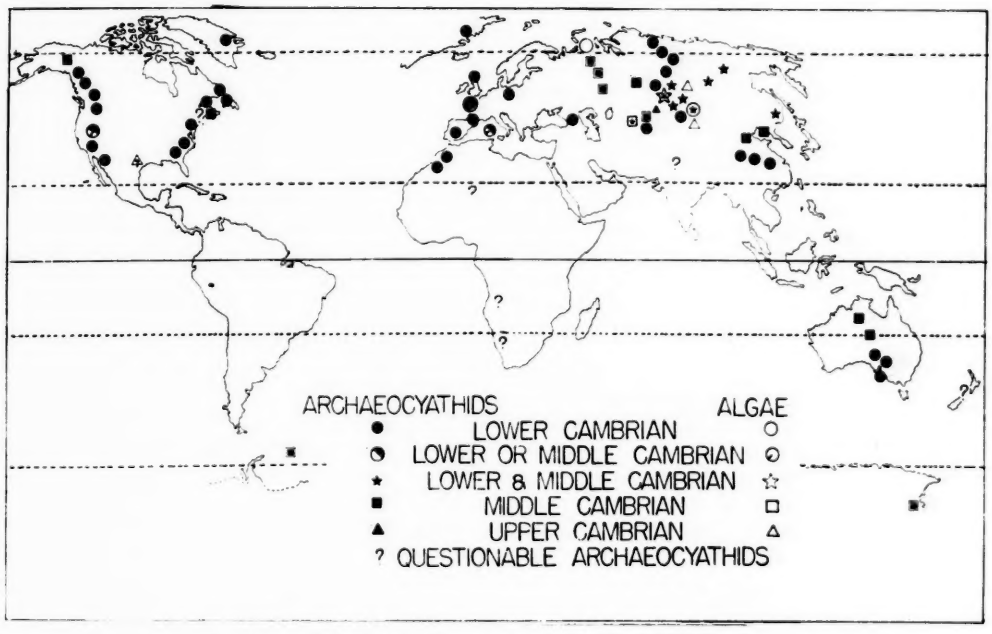
paleogeographic models for the same time interval, the paleoecologist could experimentally determine which circulation pattern best satisfies his paleobiogeographic distributions and climatic inferences. He could, of course, do the same thing with a crayon on a globe, or with pencil and paper, although it is reassuring to see the dynamic details on selected rotating models. Such an approach, with suitable meteorologic and oceanographic guidance, could greatly improve the basis of paleoclimatology and test the relative probability within given factual frameworks of apparent polar wandering, continental drift, or stability of the outer crust and continents at various times in the past.

This has yet to be done in a critical way for any reasonably short time interval, but some data have been plotted on the distribution of presumably warm-water organisms in Cambrian, Devonian, Permian, and other times. Stehli (1957) did this on a mercator projection for various fusulines (text-fig. 10) and reef-living brachiopods of the Permian and concluded that there was no polar displacement during or since Permian time. My associates Helen Duncan and Majorie Arnold have plotted similar distribution patterns for the archaeocyathid-algal reef association during early and Middle Cambrian time (text-fig. 11), and for the reef- and biostrome-associated stromatoporoid *Amphipora* during Middle to Late Devonian time (text-fig. 12). Actually all three of these distribution patterns can be interpreted to suggest general parallelism to the present equator, and bulk concentration in the northern hemisphere. This could be due to the present concentration of geologically explored land in the northern hemisphere or to asymmetry of climatic belts. The presence of Cambrian archaeocyathid-algal reefs in Antarctica, however, seems to require either world-wide genial climate, markedly different circulation patterns from those of the present day, or polar displacement.

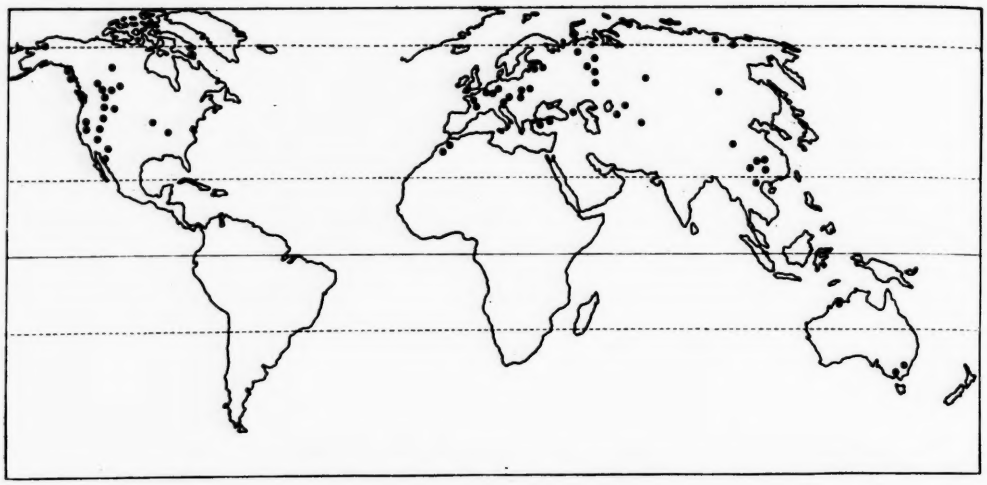
When they are plotted on a globe, without allowing for deflection or distortion, it is seen that the distribution patterns of the Cambrian reefs and Devonian *Amphipora* could be explained on the assumption of an equatorial axis running through the present poles and about along meridians 75° E. and 105° W. This would put one pole on the present equator just southwest of Liberia and the other near the phosphate island of Nauru in the mid Pacific. According to Flower (1946, p. 127) a similar pattern would fit the distribution of Middle and Upper Ordovician nautiloids, with one of the poles "somewhere in Africa," and



TEXT-FIG. *10*—Geographic distribution of selected fusuline associations in Permian rocks (after Stehli, 1957, fig. 4).



TEXT-FIG. *11*—Geographic distribution of Cambrian archaeocyathids and filamentous algae (compiled by Helen Duncan and Marjorie Arnold).



TEXT-FIG. *12*—Geographic distribution of the Middle and Upper Devonian tubular stromatoporoid *Amphipora* (compiled by Helen Duncan).

Spjeldnaes (1958) puts the Ordovician south pole at the same site southwest of Liberia as would be indicated for one of the Cambrian and Devonian poles *if* polar wandering or crustal shift is the preferred explanation. Stehli's Permian data are also consistent with polar displacement in the same direction, which would suit the picture of late Paleozoic glaciation in Africa and Australia well enough, but which would be at odds with glaciation of the same age in Pakistan. Zalessky (1938) puts the Carboniferous and Permian south poles off the southern tip of Africa on the basis of plant distribution, rejecting both drifting continents and the climatic implications of evaporites; but Barghoorn (1953, p. 241) finds that Carboniferous plants indicate "slight climatic zonation."

The paleontological evidence is not yet sufficiently well understood to be conclusively used either in support of or in opposition to polar displacement in Paleozoic time. The data as a whole need more rigorous analysis and comparison, including a review of the evidence for widespread late Paleozoic glaciation to see whether any of this might be the result of some other form of mass movement. Brooks (1949, p. 247–262), moreover, has evolved an ingenious geographic-meteorologic explanation for late Paleozoic glaciation in the southern hemisphere and equatorial regions that fits the Gondwanaland paleogeographic model without any change of present polar sites and without contradicting the evidence of widely uniform climate presented by the general absence of growth rings in late Paleozoic woods. He calls on the influence of orientation and elevation of the land on ocean and air currents to produce excessive snow-fall at high equatorial elevations from moist air that moved northward up a regional Gondwanaland slope into a low pressure realm of adiabatic cooling.

It is of interest in this connection also (text-fig. 13) to consider the northern hemisphere distribution of salt and related evaporites through Paleozoic and later geologic time as summarized by Lotze (1957, p. 192–193). From Permian to Recent time these line up in a broad belt or belts parallel to the present equator, and consistent with the formation of salt deposits mainly in the horse latitudes of variable winds and large evaporation, or in the prevailing westerlies after great loss of moisture following travel over wide or high land areas. This is also consistent with the conclusion of Simpson (1953, p. 60–63) from the vertebrate evidence, Ransom (1950) from data on coral distribution, earlier summarized by Vaughan and Wells (1943, p. 69–75), and von Ihering (1927)

from a concensus of paleontological and other paleoclimatic evidence that there could have been no appreciable displacement of land masses or latitudinal belts in post-Triassic time. Even the paleomagentic evidence has been interpreted by Hospers (1955, p. 72) to indicate negligible or no polar wandering at least since Eocene time, and former strong supporters of post-Triassic polar shift (*e.g.* Graham, 1955) are now joining with other students of remanent magnetism (*e.g.* Graham, Buddington, and Balsley, 1957) to warn that the data on which their original conclusions were reached were probably biased by magnetostrictive changes induced by secondary stress. Paleotemperature data from O^{18}/O^{16} ratios for the Late Cretaceous (Epstein, 1959, p. 229) also indicate that the colder parts of the then generally mild and uniform climate were in Alaska and Siberia.

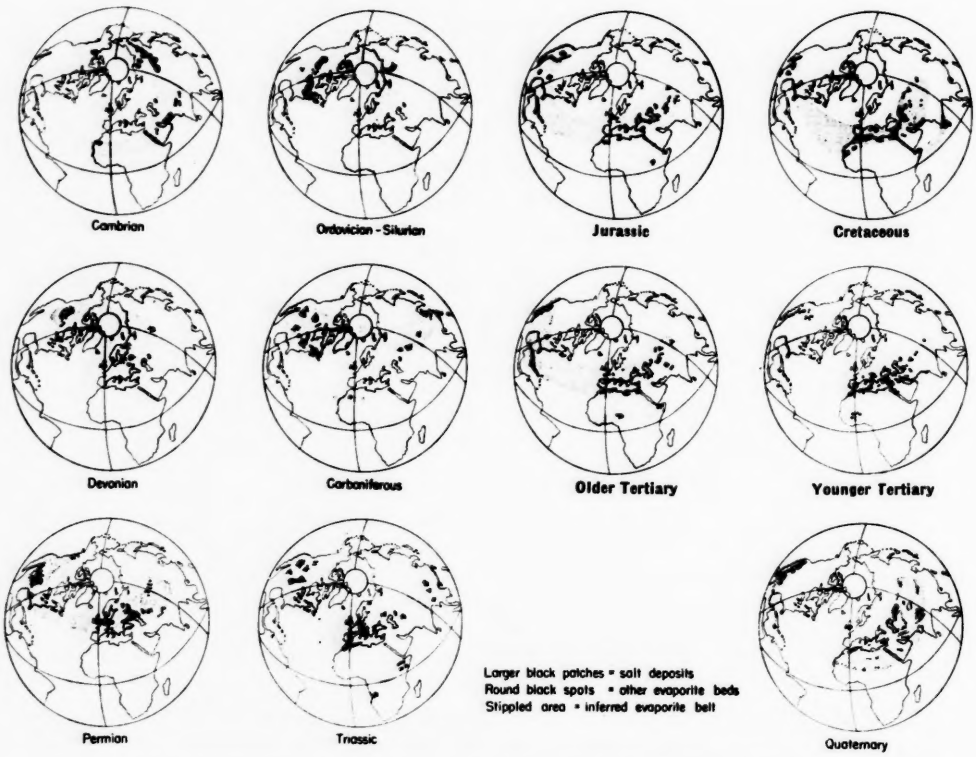
On the other hand, latitudinal deductions based on the pre-Permian patterns of salt distribution are just as equivocal as those of the presumably stenothermal fossils; they both imply either much less latitudinal differentiation and presumably warmer world climate in those times, or drastically different arrangement of its latitudinal belts!

It bears remembering that, part from solar and atmospheric variations, the total land area and its shape, distribution, and orientation profoundly affect climate. Certainly there have been warm climatic conditions in areas now at high latitudes in post-Triassic time, as there were earlier (*e.g.* Wright and Priestley, 1922, p. 429–430; Arkell, 1935; Reid and Chandler, 1933, p. 47–89; Barghoorn, 1953, p. 43; Epstein, 1959, p. 229). Brooks (1949, p. 197) finds no difficulty in visualizing the growth of "coral reefs almost to the Arctic Circle and isolated corals even farther north" during genial climatic intervals. To go further with this problem we need to enlist every available approach, from meticulous biotal and habitat analysis of all preserved types of environment, through the available methods of regional paleoclimatologic reconstruction and model research, to paleomagnetism and geochemistry—including the geochemistry of paleosols, residual ore deposits, organic concentrates, and evaporites, which can be correlated with amount and seasonal distribution of rainfall, temperature and humidity, geomorphology, and biologic factors influencing weathering and concentration of residual materials from different parent rocks (Lang, 1920, especially fig. 3; Crowther, 1930; Strakhov, 1947; Nikiforoff, 1953; Rukhin, 1955, p. 31–35).

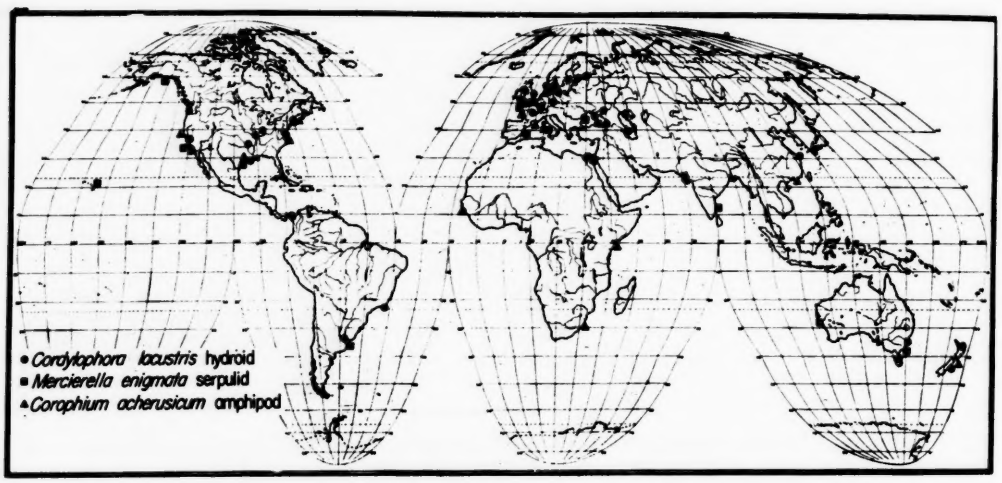
PALEOBIOGEOGRAPHY AND BIOTIC DISPERSAL

The ability of organisms to spread is one of their most important adaptive and ecologic characteristics, and the patterns they create by spreading are the basis of paleobiogeography. In a static sense this may be described as the spatial distribution of reliably identified organisms at a moment in time—the smaller the systematic units, in general, the more refined the paleobiogeography. To assume that wide geographic separation excludes the prospect of nomenclatural identity is to bias the data. In context with the inferred relations of land and sea, and the paleoecologic implications of the sediments that enclose the identified fossils, critical analysis of objective differences between biotas will suggest migration routes and dispersal mechanisms that can be compared with the land connections, current systems, and regional climatologic variation demanded by given earth models.

The manner in which some organisms become dispersed to the far corners of the earth and adapted to variant living conditions seems almost to defy the laws of probability. This is particularly true of certain estuarine species (text-fig. 14), of marine annelids, and of many fresh water mollusks, plants, insects, and arachnids (Hedgpeth, *in* Ladd et al., 1957, v. 1, p. 706; Yen, 1947; Brooks, 1950; Gislen, 1948; Glick, 1939; Schmidt, 1955 p. 786–787; Thorson, 1950). As for creatures of more restricted distribution, Simpson (1953) has discussed the mechanisms and degrees of probability for terrestrial animals, and Thorson (1950) for the marine bottom faunas. Anyone who would speculate on marine dispersal routes or the improbability of particular dispersal patterns should be aware not only of the possible effects of north-south land masses, of broad deeps, and of current systems, but should consider the great variety and even



TEXT-FIG. *13*—Distribution of evaporites in the northern hemisphere for the geologic periods since the Precambrian (after Lotze, 1957, p. 192–193).



TEXT-FIG. *14*—Geographic distribution of selected living circummundane estuarine animals (after Hedgpeth, *in* Ladd et al., 1957, v. 1, p. 706).

flexibility of possible larval adaptations favoring dispersal. The living polychaetes, for instance, have the greatest number of cosmopolitan species among the marine benthos precisely because such cosmopolitan polychaetes are able to undergo different forms of reproduction and larval development, tending to follow instinctively the pattern that will best insure dispersal according to local and temporary circumstances. Other widespread living organisms, some narrowly restricted in their adult choice of habitable conditions, are characterized as a rule by easily dispersed, long lasting early stages, and the same was doubtless true in the past.

Running briefly over the data on the most widely distributed types of organisms in modern times (and omitting migratory birds, fish, cetaceans, and the effects of man) we see that they are likely to fall in one of several categories:

1. Land plants with windborne spores.
2. Planktonic organisms, or organisms which at some stage in their lives may attach themselves to or be carried naturally within moving objects such as driftwood, pumice, seagoing vessels, cetaceans, or fish.
3. Fresh water or brackish water mollusks, plants, insects, or arachnids characterized by viviparous or parthenogenetic reproduction, or by spores and resting stages which may be transported by wind or birds and undergo long periods of estivation.
4. Organisms, such as marine annelids, with great larval and reproductive lability.
5. Species of shallow warm or temperate marine waters with longlasting planktonic larval stages, and
6. Deep and cold water species with abbreviated larval life or viviparous (including ovoviviparous) reproduction and able to move or drift with deep currents (Bruun, *in* Ladd et al., 1957, v. 1. p. 663).

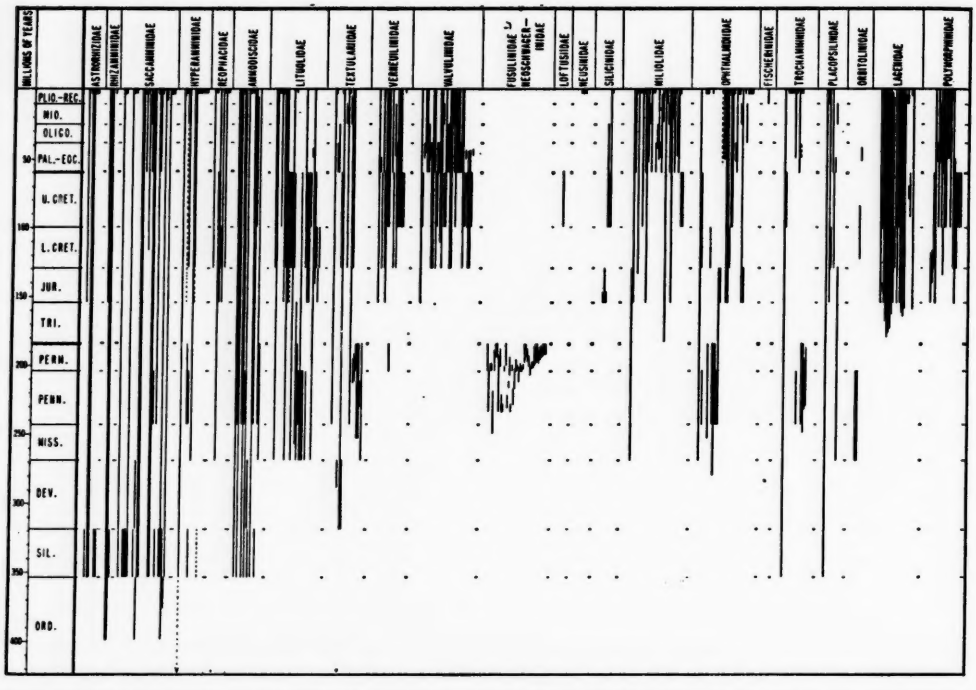
One should have good reason for eliminating the above categories, as well as the peculiarly geologic uncertainties and the statistical probability of viable freak transport, before concluding either that geographic factors require otherwise statistically similar fossil populations to belong to nomenclaturally different species or that drastic paleogeographic changes are in order (Handlirsch, 1937; Schmidt, 1955, p. 772–775). He would be justified, to be sure, in discounting the effect of pre-Jurassic birds, in insisting that prospective dispersal mechanisms provide for sufficiently frequent genetic exchange or brevity of isolation to minimize the probability of recognizable endemic speciation in long lived stocks, and in recognizing the possibility of taxonomically unavailable differences in missing soft parts.

EXTINCTION

Equal in paleoecological interest to the conditions under which organisms live are the conditions under which they will not survive. Thus, assuming the verity of the generally predicated widespread organic extinctions of the past, it is germane to the present theme to ask how and why they happened.

The data so far assembled for the two most widely postulated times of extinction—late Paleozoic and late Mesozoic (Henbest et al., 1952)—display certain probably significant similarities and differences. In both instances, the groups that disappeared (*e.g.*, text-fig. 15), seem to have made their exits at widely different times. This frequently happened, moreover, without concomitant expansion of other groups to fill the vacated niches, although these niches were later filled by different sorts of organisms. It is also curious that the supposed late Paleozoic extinctions seriously affected only the marine biotas. The late Mesozoic extinctions, on the other hand, affected sea and land animals alike, but had much less marked effect on the terrestrial floras.

Such anomalies need to be accounted for by means both efficacious and factually consistent. Thus, even while recognizing the importance of climatic change as an ecologic factor, many (*e.g.* George, 1958a, p. 415–417) have been troubled that the most frequently proposed general explanation for extinction calls on catastrophic climatic changes and habitat variations related to supposed world-wide, synchronous, short-



TEXT-FIG *15*—Approximate distribution pattern of the Foraminifera in geologic time, as represented by the published records for the first half of the listed Cushman families (after Henbest, *in* Henbest et al., 1952, fig. 1).

term orogeny. The recorded facts imply that the extinctions affected different groups of organisms at different times over geologically long intervals, and commonly during apparent orogenic calm.

It is essential, then, that the lethal effects of a workable extinction mechanism should have different threshold limits for different groups of organisms. Such effects should also be able alternatively to impinge on the total range of a vanishing species more or less catastrophically by the geologic clock, or to vary locally. The first of these corollaries is satisfied and the second partially satisfied by variations of an hypothesis calling on differences in cosmic or ultraviolet radiation due to long-term changes either in rate of emission or the earthly atmospheric screen (Wilser, 1931; Stechow, 1954; Schindewolf, 1955). Another corollary of this hypothesis that was skillfully handled by Wilser (1931, p. 173–177), but which nevertheless seems fatal to it as a general explanation, is that such radiation should affect land organisms preferentially over those living in the water and shallow water organisms more severely than those living at depth. The radiation-sensitive amphibians, in fact, paid scant attention to the Paleozoic-Mesozoic boundary, and the radiation-resistant shallow-water brachiopods and corals underwent reductions at least as severe as their sensitive associates, the cephalopods and echinoderms. Moreover, in a more general way the inhabitants of aqueous environments seem to suffer more widely and severely at times of extinction than do those that inhabit dry land.

Thus the widespread desertal conditions of Permian to Triassic time saw low terrestrial but high marine mortalities, whereas the swamp dwelling herbivorous Cretaceous dinosaurs and their predatory neighbors perished, as did the marine ammonites, without a single Tertiary holdover. This contrast in itself, however, provides the seeds of further inquiry, for in reflecting what factors might be favored by the presence of large

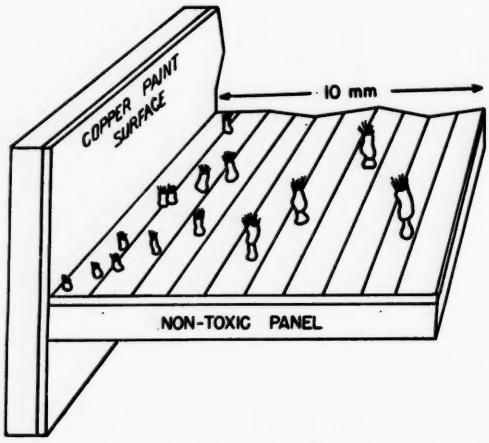
or interconnected water systems, the possibility of a chemical mechanism comes to mind. Data are presently insufficient to test this prospect satisfactorily, but it will exercise the imagination and illustrate the paleoecological and geochemical complexity of the question to explore it a bit.

For instance, the required effects could be obtained, and with the desired threshold limits and local variations, by the progressive or stepwise increase to generally lethal proportions of some normally assimilable or even needed trace element. The actual extinction of a given group of organisms might thereby be either through direct assimilation of the effective element in lethal quantities, as an indirect result of the death of essential dietary components, or as a result of overdoses via a concentrator dietary component.

Such data as are available on the distribution and general effects of trace elements in the sea are summarized by Harvey (1955, p. 138–152), in lakes by Hutchinson (1957, p. 801–835), and as specifically related to protozoa and algae by Provasoli (1958, p. 286–290). Anti-fouling studies provide further information on the relative toxicity of different metal ions to different organisms. Copper, mercury, and silver are the most highly toxic substances (Ketchum, 1952), but zinc, selenium, chlorine, arsenic, bismuth and other metal ions can also poison, stunt, and kill, with different effects on different organisms. To exemplify threshold effects, copper and mercury are about 10 times more toxic to diatoms than to bacteria, whereas zinc is about 10 times more toxic to bacteria than to diatoms. Brown algae can concentrate zinc up to factors of 1000 and titanium to factors of 10,000 over surrounding sea waters without deleterious effects (Black and Mitchell, 1952, p. 582). Algae and protozoa, at the basic nutrient level, may be so delicately attuned to their chemical environment as to be more reliable and sensitive indicators of it than chemical analyses are (Provasoli, 1958, p. 281). Higher up the nutrient ladder selenium kills cattle as a result of attaining high concentrations in some range plants Hurd-Karrer (1935). Conversely too little cobalt can have lethal effects on ruminant animals and too much is harmful to plants (Young, 1956, 1957; Johnson 1956), while molybdenum has reverse effects from cobalt (Termier & Termier, 1959, p. 158). Thus, the great herbivorous dinosaurs could have become extinct because general chemical changes either killed the swamp floras on which they fed or reached concentrations in food or water lethal to the dinosaurs (or, to be sure, because of sufficiently universal and drastic desiccation or cooling).

Consider copper. It is a good example of a widely dispersed but rare metal-ion whose concentration displays important vital and threshold effects (*e.g.* Harvey, 1955, p. 139–142; Hutchinson, 1957, p. 817–818; Provasoli, 1958, p. 287–288). It is an almost universal trace-element in the body fluids of organisms, and, in small quantities, it is essential to the survival of some. The spat of oysters settle best when copper in the water is 5 to 500 times above its normal concentration in the sea of 1 to 10 parts per billion and do poorly at lower concentrations, but concentrations as low as 30 parts per billion of ionic copper are injurious to some lacustrine phytoplankton (Hutchinson, 1957, p. 817). Many other mollusks, as well as arthropods, depend on use of the copper-bearing hemocyanin as an oxygen carrying pigment (*e.g.* Prosser et al., 1950, p. 304), while the oyster drill can be kept out of commerical oyster beds by the excess ions that diffuse from a thin encircling copper wire (McKernan, 1958). Sharks are apparently so sensitive to diffusing copper ions that copper-releasing compounds are at least locally effective shark repellants.

A note by Chu and Cutress (1955) tells of the death of all bottom living organisms within 10 hours of adding copper sulfate to an area in Hilo Harbor in proportions of about 25 mg./L $CuSO_4$, or about 10 parts per million of free cooper ion. This is only slightly more than the concentration of strontium in present sea water, but 10 times the concentration of 1 mg/L at which Harvey (1955, p. 143) indicates the concentration of cupric ions to have a generally poisonous effect on marine organisms. The potency of the effect is illustrated by an experiment reported by Ketchum (1953, p. 253), and showing the short term effect of diffusion of copper ions on developing bryozoan larvae fixed at different distances from a copper painted surface (text-fig. 16).



TEXT-FIG. *16*—Effect of diffusing copper ions on developing larvae of the marine bryozoan *Bugula* after four days exposure (after Ketchum, 1952, p. 253, fig. 12).

It is of interest, therefore, that traces of copper are found in varying amounts in sedimentary rocks of all ages. Locally it reaches ore-forming concentrations in beds whose delicate textures strongly imply syngenetic or very early diagenetic origin, as in the Precambrian Nonesuch shale of Michigan (White and Wright, 1954) or the Permian Kupferschiefer shales of central Europe (Deans, 1948). The Kupferschiefer is of special interest. It consists of bituminous shale from mainly less than 1 to 60 meters thick, having generally 0.5 to 2 percent of zinc, lead, and copper. It extends over most of Germany and far eastward towards the Urals, where copper is extensively disseminated in Permian sandstones. Kupferschiefer fossils include vast numbers of paleoniscid fishes and land plants, scattered reptilian remains, occasional Foraminifera, brachiopods, and even starfishes (Kayser, 1923, p. 365), an association that implies generally brackish waters with marine connections and intervals of normal salinity. Associated trace metals include silver, vanadium, molybdenum, nickel, cobalt, and chromium.

It has already been proposed by Abel (1912, p. 39) and Moret (1948, p. 9) that abrupt influxes of copper or silver to the Kupferschiefer sea may account for its fish mortalities, but present interest is in more widespread effects.

Suppose that copper and zinc had been delivered to the Kupferschiefer sea in volumes which after dilution were widely lethal. They would have been carried to the shallow sea floor by poisoned organisms and associated chelating substances, and also concentrated by creatures with affinity for them, such as slime films on the sediment surface (Ketchum, 1952, p. 259–261). The activity of slime films of bacteria and algae, suggested by the antipathetic relations of copper and zinc in the Kupferschiefer (Deans, 1948, p. 343) and the inverse tolerance of bacteria and algae to copper and zinc, could have periodically reduced the local concentrations of the poisonous metal ions to tolerable levels for those organisms which episodically repopulated the area from external haven sites. At the same time, diffusion of unfixed ions to contiguous seas might have steadily added them to the world ocean faster than they could be removed by the available depoisoning mechanisms which make possible the existence of marine life as we know it. Assuming, further, that the now widely held view of juvenile accretion (Rubey, 1951) of the oceans is correct, the decrease in volume of total hydrosphere with receding time would equally increase the chances of building up selectively lethal concentrations of the effective metal ions or of complexes from which they might be released.

If, then, abnormally large amounts of copper or other potentially lethal metal ions or complexes were supplied to and diffused through the Permian seas generally, this might help to explain: (1) Permian extinctions, (2) anomalies in the pattern of extinction and evolution, and (3), as might any mass extinction, c. the richness of Permian potash and phosphate deposits. An abnormal load of the critical ions in solution or released from complexing agents could explain those extinctions not attributable to a recognizable local cause such as predation, competition, or other demonstrable ecologic or climatic change; and if concentration of the destructive substance were built up gradually and from different centers, it would extinguish different organisms at

different times and with different geographical patterns, as their respective tolerances, or those of the organisms they could eat, were exceeded. Widespread marine extinctions would presumably result in potassium, phosphate, vanadium, and other biogenic elements being returned to sea water or sediments in excess of organic withdrawal and locally concentrated in favorable sites. This might account for the fact that the world's greatest potash reserves are in salt deposits of Late Permian age and for the extensive vanadium-rich Permian phosphate deposits. The Cretaceous and lower Tertiary phosphate deposts of North Africa are similarly coupled with large-scale potash return in the form of glauconite at and following another time of mass extinction. The processes of local concentration in shelf sediments presumably would be similar to those operative today in areas of upwelling from depths where organically withdrawn materials are primarily concentrated, but on a much larger scale.

Failures of Permian terrestrial faunas and floras to be significantly affected by the same underlying causes as those which wrought such havoc among the marine biotas could be explained by slow diffusion (and local absence) of the lethal substance or substances in the nonmarine environment, especially under later Permian desertal conditions. The rapid and occcasion ally bizarre evolution of various Permian marine species might reflect a high rate of mutation brought on either by direct chemical simulus or by adaptations to new food chains (effects which, of course, could equally be produced by radiation).

For the cause of Cretaceous extinctions also to have been of a basically chemical nature would be consistent with their concentration amongst marine and swamp dependent organisms—the cephalopods and the dinosaurs. Mammals, social insects, and the flowering plants presumably lived mainly on high, well drained areas which would favor their survival and therefore Tertiary expansion according to the concept outlined.

An hypothesis without testable corollaries is, of course, valueless. In the case of a chemical mechanism some of the corollaries that already seem to be satisfied were inversely mentioned earlier: the existence of threshold effects, greater incidence in the aqueous than in the terrestrial environment, widespread geologically short-termed effects with some geographic irregularities but few or no real haven areas. Corollaries that remain to be tested include (1) the relationship between well documented and dated extinctions and general concentration and rate of buildup of possibly critical substances as a primary component of the sedimentary column, and (2) the relative sensitivity of surviving relatives of eliminated and unaffected groups and their usual food sources to abnormally concentrated sedimentary metals of the same age. Available data on these relations are insufficient. Much additional information is needed on the distribution and probable sources of syngenetic trace metals in the sedimentary column, the fluid chemistry of ions and complexes of these metals, the history of sea water, the existence and specific dating of supposed extinction episodes or events, and the inter-dependency and threshold levels for different metal ions of many kinds of organisms. More specific corollaries should be formulated and tested if they can be found.

Although, moreover, I have by way of illustration discussed mainly the effects of chemical excess, the possible paleoecological significance of trace element fluctuation should be extended to include all deviation above or below a given organism's requirements or tolerances (*e.g.*, Salmi in Schatz, 1957, p. 26). Local transfer effects are to be kept in mind, whereby the ecological and evolutionary consequences of trace element deficiencies created by concentrator plants in a terrestrial environment might be paralleled by the effects of excesses of the same trace elements in the aquatic environment as a result of downslope movement. Even the possibility of significant variation in the gross chemical composition of sea water is hinted at by the relative abundance of Permian salt and the high incidence of marine extinctions among groups that do not tolerate reduced salinity. And, finally, it is safe to predict that if the ultimate truth about extinction is ever known, no simple one-component system will explain all facets of all extinctions detected, any more than

other complex natural phenomena have simple explanations. Certainly climatic variations (in moisture, temperature, atmospheric gasses etc.), due to a variety of causes and in a variety of ways, can and do lead to important and far-reaching changes in organic communities—directly (*e.g.* Dubois, 1895, p. 56–59, 147–148), as well as through their effects on the conditions of regional runoff and its chemical composition. Biotal changes resulting from prolonged droughts within historic time illustrate this as graphically as the effect of biogeographical factors is illustrated by the competitive elimination of South American marsupial carnivores following the arrival of more efficient placental counterparts in the late Tertiary (Romer, 1945, p. 319–320), the predatory destruction of the Great Lakes trout fishery upon the introduction of the normally marine lamprey in 1945–1946 (Edinger, 1956, p. 22), or the extinctions that followed the rise of man and are still taking place.

Like all hypotheses in paleoecology and other subjects, that of chemical extinction will serve a useful purpose if it does no more than provide basis for the fruitful extension of inquiry, or for effort toward better correlation of heretofore seemingly unrelated facts.

REFERENCES CITED*

ABEL, OTHENIO, 1912, Grundzuge der Palaeobiologie der Wirbeltiere: Stuttgart, Schweizerbart, 708 p.

——, 1935, Vorzeitliche Lebensspüren: Jena, Gustav Fischer, 644 p.

ABELSON, P. H., 1959, Geochemistry of organic substances, *in* Abelson, P. H. (ed.), Researches in geochemistry (511 p.): New York, John Wiley & Sons, Inc., p. 79–103, figs. 1–4.

ADAMS, C. B., 1852, Catalogue of shells collected at Panama, with notes on synonymy, station, and habitat: Ann. Lyceum Nat. Hist. N. Y., v. 5, p. 229–567.

ADAMS, J. E., & FRENZEL, H. N., 1950, Capitan barrier reef, Texas and New Mexico: Jour. Geology, v. 48, p. 289–312, fig. 1, pls. 1,2.

ALIZADYE, K. A., 1954, Akchagyl strata of Azerbaijan (in Russian): Akad. Nauk Azerb. S.S.R., 344 p. (Ализаде, К. А., 1954, Акчагыльский ярус Азербайджана: Акад. Наук Азерб. С.С.Р., 344 стр.)

* Although about 200 publications are here cited, the list is by no means exhaustive. Indeed it leaves out many familiar and fundamental references in elementary ecology. Fuller bibliographies are given in references listed on p. 928.

ALLEE, W. C., EMERSON, A. E., PARK, ORLANDO, PARK, THOMAS, & SCHMIDT, K. P., 1949, Principles of animal ecology: Philadelphia, W. B. Saunders Co., 837 p.

ARKELL, W. J., 1935, On the nature, origin and climatic significance of the coral reefs in the vicinity of Oxford: Geol. Soc. London Quart. Jour., v. 41, p. 77–110, pl. 6.

ARKHANGUELSKY, A. D., 1930, Slides of sediments on the Black-sea bottom and the importance of this phenomenon for geology: Soc. Imperiale Nat. Moscow Bull., sec. geol. (Bull. Moskva obshch. pirody, otd. geol.), v. 8, no. 1–2 (n.s. v. 38), p. 32–79,80, figs. 1–20, pls. 1–4.

AXELROD, D. I., 1952, A theory of angiosperm evolution: Evolution, v. 6, no. 1, p. 29–60, figs. 1–14.

——, 1956, Mio-Pliocene floras from west-central Nevada: Univ. Calif. Pub. Geol. Sci., v. 33, 322 p.

——, 1958, Evolution of the Madro-Tertiary geoflora: Botanical Rev., v. 24, no. 7, p. 433–509, figs. 1–10.

BAILEY, I. W., & SINNOTT, E. W., 1916, The climatic distribution of certain types of angiosperm leaves: Am. Jour. Botany, v. 3, p. 24–39.

BARGHOORN, E. S., 1953, Evidence of climatic change in the geologic record of plant life, *in* Shapley, Harlow (ed.), Climatic change: Cambridge, Mass., Harvard Univ. Press, ch. 20, p. 235–248, figs. 1–3.

BEMMELEN, R. W. VAN, 1949, The geology of Indonesia. Vol. 1A, General geology of Indonesia: The Hague, Martinus Nijhoff, 732 p.

BERRY, E. W., 1945, The beginnings and history of land plants: The Johns Hopkins Univ., Studies in Geol. no. 14, p. 9–91, figs. 1–12.

BLACK, W. A. P., & MITCHELL, A. L., 1952, Trace elements in the common brown algae and sea water: Jour. Marine Biol. Assoc. U. K., v. 30, p. 575–584.

BOURCART, JACQUES, 1957, Premier rapport sur les fonds meubles de la Baie du Mont Saint-Michel: Com. Central d'Oceanog. et d'Étude des Côtes, Bull. d'Inf., tome 9, no. 6, p. 325–336, pls. 1,2.

BRADLEY, J. S., 1957, Differentiation of marine and sub-aerial sedimentary environments by volume percentage of heavy minerals, Mustang Island, Texas: Jour. Sed. Petrology, v. 27, no. 2, p. 116–125, figs. 1–12.

BRADLEY, W. H., 1948, Limnology and the Eocene lakes of the Rocky Mountain region: Geol. Soc. America Bull., v. 59, no. 7, p. 635–648, figs. 1–6.

BRADLEY, W. H., ET AL., 1942, Geology and biology of North Atlantic deep-sea cores between Newfoundland and Ireland: U. S. Geol. Survey Prof. Paper 196, 163 p.

BROOKS, C. E. P., 1949, Climate through the ages: New York, McGraw-Hill, Inc., 395 p.

BROOKS, J. L., 1950, Speciation in ancient lakes: Quart. Rev. Biology, v. 25, no. 1, p. 30–60, 131–176, figs. 1–8.

BROWN, BARNUM, & VOKES, H. E., 1944, Fossil imprints of unknown origin; 2, Further infor-

mation and a possible explanation: Am. Jour. Sci., v. 242, no. 12, p. 656–672, fig. 1, pls. 1–4.

BRUSH, L. M., JR., 1958, Study of cross-stratification in a large laboratory flume: Geol. Soc. America Bull., v. 69, no. 12, p. 1542.

CAIN, S. A., 1944, Foundations of plant geography: New York & London, Harper & Sons, 556 p.

CARPENTER, F. M., 1953, The geological history and evolution of insects: *in* Science in progress, 8th ser. (G. A. Baitsell, ed.), Yale Univ. Press, p. 71–89,269–270, figs. 23–29.

CHANEY, R. W., 1940, Tertiary forests and continental history: Geol. Soc. America Bull., v. 51, no. 3, p. 469–488.

——, 1949, Early Tertiary ecotones in western North America: Natl. Acad. Sci. Proc., v. 35, no. 7, p. 356–359.

CHU, G. W. T. C., & CUTRESS, C. E., 1955, Dermatitis due to contact with the hydroid *Syncoryne mirabilis* (Agassiz, 1862): Hawaiian Med. Jour., v. 14, p. 403–404, figs. 1–4.

CLARKE, JOHN M., 1921, Organic dependence and disease; their origin and significance: N. Y.: State Mus. Bull., nos. 221–222, 113 p.

CLEMENTS, F. E., & SHELFORD, V. E., 1939, Bioecology: New York, John Wiley & Sons, 425 p.

CLOUD, P. E., JR., 1948, Some problems and patterns of evolution exemplified by fossil invertebrates: Evolution, v. 2, no. 4, p. 322–350, figs. 1–4, pls. 1–4.

——, 1952, Facies relationships of organic reefs: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 11, p. 2125–2149, figs. 1–4.

——, 1955, Physical limits of glauconite formation: Am. Assoc. Petroleum Geologists Bull., v. 39, no. 4, p. 484–492.

——, 1959, Geology of Saipan, Mariana Islands. Submarine topography and shoal-water ecology: U. S. Geol. Survey Prof. Paper 280-K, p. 361–445, figs. 36–43, pls. 120–139.

CLOUD, P. E., JR., & BARNES, V. E., 1948, The Ellenburger group of Central Texas: Univ. Texas, Bur. Econ. Geology Pub. 4621, 474 p.

CRAIG, G. Y., 1952, A comparative study of the ecology and paleoecology of *Lingula:* Edinburgh Geol. Soc. Trans., v. 15, p. 110–120, figs. 1,2, pl. 4.

——, 1956, The mode of life of certain Carboniferous animals from West Kirkton quarry, near Bathgate: Edinburgh Geol. Soc. Trans., v. 16, pt. 3, p. 272–279, fig. 1.

CROWTHER, E. M., 1930, The relationship of climatic and geological factors to the composition of soil clay and the distribution of soil types: Royal Soc. London Proc., sec. B, Biol. Sci., v. 107, p. 1–30.

DANOIS, ÉDOUARD LE, 1948, Les profondeurs de la mer. Trente ans de recherches sur la faune sous-marine au large des côtes de France: Paris, Payot, 303 p.

DEANS, T., 1948, The Kupferschiefer and associated lead-zinc mineralization in the Permian of Silesia, Germany and England: 18th Internatl. Geol. Cong. (London) Rept., pt. 7, p. 340–352, figs. 85–87.

DEBYSER, J., VATAN, ANDRÉ, & BOYER, F., 1955, La sédimentation sableuse sur la côte atlantique entre la Loire et le Bassin d'Arcachon: Geol. Rundschau, v. 43, p. 406–425.

DEEVEY, E. S., JR., 1953, Paleolimnology and climate, *in* Shapley, Harlow (ed.), Climatic change: Cambridge, Mass., Harvard Univ. Press, ch. 22, p. 273–318, figs. 1–9.

DEFLANDRE, GEORGES, 1936, Les flagellés fossiles, Aperçu biologique et paléontologique, Role géologique: Paris, Hermann et Cie., Actualités Scientifiques et Industrielles, 335, Exposés de Géologie, 97 p.

DEGENS, E. T., WILLIAMS, E. G., & KEITH, M. L., 1957, Environmental studies of Carboniferous sediments, Part I. Geochemical criteria for differentiating marine and freshwater shales: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 11, p. 2427–2455.

——, 1958, Environmental studies of Carboniferous sediments, Part II. Application of geochemical criteria: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 5, p. 981–997, figs. 1–5.

DUBOIS, EUGENE, 1895. The climates of the geological past, and their relation to the evolution of the sun: London, Swan, Sonnenschein & Co., 167 p.

EDINGER, TILLY, 1956, Objets et résultats de la paléoneurologie: Ann. Paléont., T. 42, p. 95–116 figs. 1–18.

EMERY, K. O., & RITTENBERG, S. C., 1952, Early diagenesis of California basin sediments in relation to origin of oil: Am. Assoc. Petroleum Geologists Bull, v. 36, no. 5, p. 735–806, figs. 1–30.

ENGELHARDT, WOLF VON, 1940, Die Unterscheidung wasser- und windsortierter Sande auf Grund der Korngrössenverteilung ihre leichten und schweren Gemengteile: Chemie der Erde, v. 12, p. 445–465, figs. 1–4.

EPSTEIN, SAMUEL, 1959, The variations of the O^{18}/O^{16} ratio in nature and some geologic implications, *in* Abelson, P. H. (ed.), Researches in geochemistry (511 p.): New York, John Wiley & Sons, Inc., p. 217–240, figs. 1–4.

FENTON, C. L., & Fenton, M. A., 1934, *Arthraria*-like markings made by annelids and snails: Pan-Am. Geologist, v. 61, no. 4, p. 264–266, fig. 14, pl 18, fig. B.

——, 1937, Trilobite "nests" and feeding burburows: Am. Midland Naturalist, v. 18, no. 3, p. 446–451, figs. 1–6.

——, 1952, Giants of geology: Garden City, N. Y., Doubleday & Co., Inc., 333 p.

FLOWER, R. H., 1946, Ordovician cephalopods of the Cincinnati Region. Pt. I: Bull. Am. Paleontology, v. 29, no. 116, 751 p., 22 figs., 20 pls.

——, 1955, Trails and tentacular impressions of orthoconic cephalopods: Jour. Paleontology, v. 29, no. 5, p. 857–867, figs. 1–4.

FOERSTE, A. F., 1930, The color patterns of fossil cephalopods and brachiopods, with notes on gastropods and pelecypods: Mich. Univ., Mus. Paleontology Contr., v. 3, no. 6, p. 109–150, pls. 1–5.

FONDEUR, CATHERINE, GOTTIS, MAURICE, ROUIRE, JACQUES, & VATAN, ANDRÉ, 1954, Quelques aspects de la dolomitisation au Juras-

sique en France: 19e Internatl. Geol. Cong. (Algerie) Comptes rendus, sec. 13, fasc. 15, p. 471–491, figs. 1–10.

FORBES, M. E., 1844, Report on the Mollusca and Radiata of the Aegean Sea, and on their distribution, considered as bearing on geology: British Assoc. Adv. Sci., Rept. 13th Mtg., p. 130–193.

FORBES, M. E., & GODWIN-AUSTEN, ROBERT, 1859, The natural history of the European Seas: London, John van Voorst, 306 p.

FUCHS, THEODOR, 1895, Studien über fucoiden und hieroglyphen: Denkschr. Kaiserlichen Akad. Wiss. Wien, Math-Naturw. Cl., Bd. 62, p. 369–448, figs. 1–22, pls. 1–9.

GARRELS, R. M., 1954, Mineral species as functions of pH and oxidation-reduction potentials, with special reference to the zone of oxidation and secondary enrichment of sulfide ore deposits: Geochim. et Cosmochim. Acta, v. 5, no. 4, p. 153–168, figs. 1–5.

GEORGE, T. N., 1957, Sedimentary processes and structures: Sci. Progress, v. 45, no. 178, p. 278–292.

——, 1958a, Rates of change in evolution: Sci. Progress, v. 46, no. 183, p. 409–428.

——, 1958b, The ecology of fossil animals: Sci. Progress, v. 46, no. 184, p. 677–690.

GILBERT, G. K., 1890, Lake Bonneville: U. S. Geol. Survey Mon. 1, 493 p.

——, 1914, The transportation of debris by running water: U. S. Geol. Survey Prof. Paper 86, 263 p.

GINSBURG, R. N., & LOWENSTAM, H. A., 1958, The influence of marine bottom communities on the depositional environment of sediments: Jour. Geology, v. 66, no. 3, p. 310–318, figs. 1–5, pls. 1,2.

GISLEN, TORSTEN, 1947, Aerial plankton and its conditions of life: Biol. Reviews, v. 23, p. 109–126.

GLICK, P. A., 1939, The distribution of insects, spiders, and mites in the air: U. S. Dept. Agr. Tech. Bull. 673, p. 1–151, figs. 1–5, pls. 1–5.

GOLDRING, WINIFRED, 1922, The Champlain Sea: N. Y. State Mus. Bull., nos. 239–204, p. 153–194, figs. 1,2, pls. 1–5.

GRABAU, A. W., 1913, Principles of stratigraphy: New York, A. G. Seiler & Co., 1183 p.

GRAHAM, J. W., 1955, Evidence of polar shift since Triassic time: Jour. Geophysical Research, v. 60, no. 3, p. 329–347, figs. 1–7.

GRAHAM, J. W., BUDDINGTON, A. F., & BALSLEY, J. R., 1957, Stress-induced magnetizations of some rocks with analyzed magnetic minerals: Jour. Geophysical Research, v. 62, no. 3, p. 465–474, figs. 1,2.

HALDANE, J. B. S., 1957, Genesis of life, *in* Bates, D. R. (ed.), The earth and its atmosphere: New York, Basic Books, Inc., ch. 17, p. 287–301.

HALL, JAMES, 1843, Survey of the Fourth Geological District: Geology of New York, pt. 4, 683 p.

HANDLIRSCH, ANTON, 1937, Neue Untersuchungen über die fossilen Insekten mit Ergänzungen und Nachträgen sowie Ausblicken auf phylogenetische, palaeogeographische und allgemein biologische Probleme: Ann. Naturhist. Mus. Wien, Bd. 48, 140 p.

HÄNTSCHEL, WALTER, 1956, Rückschau auf die logischen und neontologischen Ergebnisse der Forschungsanstalt Senckenberg am Meer: Senckenbergiana Lethaea, Bd. 37, no. 3/4, p. 319–330.

HARVEY, H. W., 1955, The chemistry and fertility of sea waters: Cambridge Univ. Press, 224 p.

HAWKINS, H. L., 1943, Evolution and habit among the Echinoidea: Some facts and theories: Geol. Soc. London Quart. Jour., v. 99, pts. 1 and 2, nos. 393–394, p. 52–75.

HECKER, R. TH., 1957, Introduction to paleoecology (in Russian): Gosudarstvennoe Nauchno-Tekhnicheskoe Izdatelstvo, Literatury po geologii i okhrane nedr, 125 p. (Геккер, Р. Ф., 1957, Введение В палеозкологию: Государственное Научно-Техническое Издательство, литературы по Геологии и Охране Недр, 125 стр.)

HENBEST, L. C., ET AL., 1952, Distribution of evolutionary explosions in geologic time: Jour. Paleontology, v. 26, no. 3, p. 299–394.

HOSPERS, J., 1955, Rock magnetism and polar wandering: Jour. Geology, v. 63, no. 1, p. 59–74, fig. 1.

HOUGH, J. L., 1958, Fresh-water environment of deposition of Precambrian banded iron formation: Jour. Sed. Petrology, v. 28, no. 4, p. 414–430, figs. 1–3.

HOWELL, B. F., 1945, *Skolithos*, *Diplocraterion*, and *Sabellites* in the Cambrian Antietam sandstone of Maryland: Wagner Free Inst. Sci. Bull., v. 20, p. 33–40, pls, 1.2.

HOWELL, B. F., & HUTCHINSON, R. M., 1958, New lower Paleozoic coelenterate from Washington: Wagner Free Inst. Sci. Bull., v. 33, p. 13–14, pls. 1,2.

HURD-KARRER, 1935, Selenium absorption by plants and their resulting toxicity to animals: Smithsonian Ann. Rept., v. 239, p. 289–301, pls. 1–6.

HUTCHINSON, G. E., 1957, A treatise on limnology. Vol. 1, Geography, physics, and chemistry: New York, John Wiley & Sons, Inc., v. 1, 1015 p.

IHERING, H. VON, 1927, Das Klima der Tertiarzeit: Leipzig, Zeitschr. Geophys., Jahrg. 3, heft 7, p. 365–368.

INGERSON, EARL, 1953, Nonradiogenic isotopes in geology: A review: Geol. Soc. America Bull., v. 64, no. 3, p. 301–374, figs. 1–6.

Ivanova, E. A., 1958, Relations between faunal development and habitat (in Russian): Akad. Nauk, S.S.S.R., Paleont. Inst., Trudy, v. 69, 303 p. (ИВАНОВА, Е. А., 1958, РАЗВИТИЕ ФАУНЫ В СВЯЗИ С УСЛОВИЯМИ СУЩЕСТВОВАНИЯ: АКАД. НАУК С.С.С.Р., ТРУДЫ ПАЛЕОНТОЛОГИЧЕСКОГО ИНСТИТУТА, ТОМ 69, 303 стр.)

JAMES, H. L., 1954, Sedimentary facies of iron-mineral formation: Econ. Geology, v. 49, p. 235–293.

JEKELIUS, ERICH, 1932, Die Molluskenfauna der

dazischen Stufe der Beckens von Braşov: Instit. Geol. Roman. Mem., v. 2, 118, p.

JOHNSON, A. W. & TODD, ALEXANDER, 1956, Vitamin B_{12}: Endeavour, v. 15, p. 29–33, figs. 1–5.

KAYSER, EMANUEL, 1923, Lehrbuch der geologischen Formationskunde: Stuttgart, Ferdinand Enke, Bd. 2, 532 p.

KEITH, M. L., & DEGENS, E. T., 1959, Geochemical indicators of marine and fresh-water sediments, *in* Abelson, P. H. (ed.), Researches in geochemistry (511 p.): New York, John Wiley & Sons, Inc., p. 38–61, figs. 1–5.

KETCHUM, B. H., 1952, The prevention of fouling with toxics, in Marine fouling and its prevention: Woods Hole Oceanog. Inst. Rept., U. S. Naval Inst., Annapolis, Md., ch. 14, p. 241–263, figs. 1–16.

KING, P. B., 1948, Geology of the southern Guadalupe Mountains, Texas: U. S. Geol. Survey Prof. Paper 215, 183 p.

KNIGHT, J. B., 1934, A salt-marsh study: Am. Jour. Sci., ser. 5, v. 28, p. 161–181, figs. 1–5.

KRAUSKOPF, K. B., 1955, Sedimentary deposits of rare metals: Econ. Geology, 50th Anniv. Vol., p. 411–463.

KRUMBEIN, W. C., & GARRELS, R. M., 1952, Origin and classification of chemical sediments in terms of pH and oxidation-reduction potentials: Jour. Geology, v. 60, no. 1, p. 1–33, figs. 1–8.

KSIAZKIEWICZ, MARIAN, 1958, Sedimentation in the Carpathian flysch sea: Geol. Rundschau, Bd. 47, heft 1, p. 418–425, figs. 1,2.

KUENEN, PH. H., 1957, Sole markings of graded graywacke beds: Jour. Geology, v. 65, no. 3, p. 231–258, figs. 1–22.

KUENEN, PH. H., ET AL., 1950, Waddensymposium: Tijdschr. Koninkl. Nederlansch Aardrijksk. Genoot., 148 p.

KUENEN, PH. H., & SANDERS, J. E., 1956, Sedimentation phenomena in Kulm and Flozleeres graywackes, Sauerland and Oberharz, Germany: Am. Jour. Sci., v. 254, p. 649–671, figs. 1–4.

LADD, H. S., 1959, Ecology, paleontology, and stratigraphy: Science, v. 129, no. 3341, p. 69–78, figs. 1–6.

LADD, H. S., ET AL., 1957, Treatise on marine ecology and paleoecology: Geol. Soc. America Mem. 67, v. 1, Ecology (J. W. Hedgpeth, ed.), 1296 p.; v. 2, Paleoecology (H. S. Ladd, ed.), 1077 p.

LANDSBERG, H. E., 1958, Trends in climatology: Science, v. 128, no. 3327, p. 749–758, figs. 1–7.

LANG, RICHARD, 1920, Verwitterung und Bodenbildung als Einführung in die Bodenkunde: Stuttgart, E. Schweizerbart'sche Verlagsbuchhandlung, 186 p.

LASAREFF, P., 1929, Sur un méthode permettant de démontrer la dépendence des courants océaniques des vents alizés et sur le rôle des courants océaniques dans le changement du climat aux époques géologiques: Beitr. Geophys., v. 21, p. 215.

LECOMPTE, MARIUS, 1957, Les récifs Dévoniens de la Belgique: Soc. Géol. France Bull., 6e sér., tome 7, p. 1045–1068, figs. 1–8.

LEMCHE, HENNING, 1957, A new living deep-sea mollusk of the Cambro-Devonian class Monoplacophora: Nature, v. 179, p. 413–416, figs. 1–4.

LESSERTISSEUR, JACQUES, 1955, Traces fossiles d'activité animale et leur signification paléobiologique: Soc. Géol. France Mém., n.s., tome 34, fasc. 4, 150 p.

LOTKA, A. J., 1925, Elements of physical biology: Baltimore, Williams & Wilkens, 460 p.

LOTZE, FRANZ, 1957, Steinsalz und Kalisalze, Teil I: Berlin, Gebrüder Borntraeger, 465 p.

LOWENSTAM, H. A., & EPSTEIN, SAMUEL, 1954, Paleotemperatures of the post-Aptian Cretaceous as determined by the oxygen isotope method: Jour. Geology, v. 62, no. 3, p. 207–248.

MACGINITIE, G. E., & MACGINITIE, NETTIE, 1949, Natural history of marine animals: New York, McGraw-Hill Book Co., Inc., 473 p.

MATHER, KIRTLEY F., & MASON, SHIRLEY, L., 1939, A source book in geology: New York, McGraw-Hill Book Co., Inc., 702 p.

MATTHEW, W. D., 1939, Climate and evolution, 2nd ed. revised, enlarged, and supplemented by others: New York Acad. Sci., Spec. Pub., v. 1, 223 p.

MCKERNAN, D. L., 1958, Statement, *in* Review of Fish and Wildlife Service: Hearings before the Com. on Merchant Marine and Fisheries, House of Representatives, 85th Cong., 2nd sess., U. S. Govt. Printing Office, p. 44.

MOODIE, R. L., 1923, Paleopathology; an introduction to the study of ancient evidences of disease: Univ. Illinois Press, 567 p.

MOOK, C. C., 1916, A study of the Morrison formation: New York Acad. Sci. Annals, v. 27, p. 39–191, figs. 1–94, pl. 6.

MORET, LÉON, 1948, Manuel de paléontologie animale: Paris, Masson et Cie., 675 p., 241 figs., 12 tables.

——, 1952, Embranchement des spongaires: Paris, Masson et Cie., Traité de paléontologie, tome 1, p. 333–374, figs. 1–22.

MYERS, G. S., 1949, Salt tolerance of fresh-water fish groups in relation to zoogeographical problems: Bijdragen tot de Dierkunde, Bd. 28, p. 315–322.

NEWELL, N. D., ET AL., 1953, The Permian reef complex of the Guadalupe Mountains region, Texas and New Mexico: San Francisco, W. H. Freeman & Co., 236 p.

NIKIFOROFF, C. C., 1953, Pedogenic criteria of climatic changes, *in* Shapley, Harlow (ed.), Climatic change: Cambridge, Mass., Harvard Univ. Press, ch. 15, p. 189–200.

OLSON, E. C., 1948, A preliminary report on vertebrates from the Permian Vale formation of Texas: Jour. Geology, v. 56, no. 3, p. 186–198.

——, 1952, The evolution of a Permian vertebrate chronofauna: Evolution, v. 6, no. 2, p. 181–196, figs. 1–5.

——, 1957, Size-frequency distribution in samples of extinct organisms: Jour. Geology, v. 65, no. 3, p. 309–333, figs. 1–17.

OMMANNEY, F. D., 1949, The ocean: London, Oxford Univ. Press, 238 p.

D'ORBIGNY, C. A., 1820, Essai sur les plantes marines des côtes du Golfe de Gascogne, et particulièrment sur celles du departement de la Charente-Inferieure: Mus. Hist. Nat. Paris Mém., tome 6, p. 163–203.

PALMER, A. R., 1957, Miocene arthropods from the Mojave Desert, Calif.: U. S. Geol. Survey Prof. Paper 294-G, p. 237–280, figs. 84–101, pls. 30–34.

PEABODY, FRANK E., 1948, Reptile and amphibian trackways from the Lower Triassic Moenkopi formation of Arizona and Utah: Univ. Calif. Pubs., Bull. Dept. Geol. Sci., v. 27, no. 8, p. 295–468, figs. 1–40, pls. 23–45.

PÉRÈS, J. M., 1957, Essai de classement des communautés benthiques marines du gobe: Recueil des travaux de la Sta. Marine d'Endoume, fasc. 22, p. 23–53.

PÉRÈS, J. M., & PICARD, J., 1955, Biotopes et biocoenoses de la Méditerranée Occidentale comparés à ceux de la Manche et de l'Atlantique Nord-Oriental: Archives de Zoologie Expérimentale et Générale, tome 92, fasc. 1, 70 p.

——, 1958, Manuel de bionomie benthique de la mer Méditerranée: Gap, France, Imprimerie Louis-Jean, 122 p.

PIRIE, N. W., 1954, On making and recognizing life: Penquin Books, New Biology, v. 16, p. 41–53.

PROSSER, C. L., BISHOP, D. W., BROWN, F. A., JR., JAHN, T. E., & WULFF, W. J., 1950, Comparative animal physiology: Philadelphia and London, W. B. Saunders & Co., 888 p.

PROVASOLI, LUIGI, 1958, Nutrition and ecology of protozoa and algae: Ann. Rev. Microbiol., v. 12, p. 279–308.

RANKAMA, KALERVO, 1947, On the geochemistry of colombium: Science, v. 106, p. 13–15.

——, 1948, On the geochemistry of niobium: Ann. Acad. Sci. Fennicae, ser. A, III. Geol.-Geog., v. 13, 57 p.

RANSOM, GILBERT, 1950, Géonomie, écologie et répartition géographique des coraux constructeurs de récifs-Coraux et climates: Comptes rendu Soc. Biogéogr., no. 235, p. 78–88.

REID, E. M., & CHANDLER, M. E. J., 1933, The London clay flora: British Mus. (Nat. History), 561 p.

REINECK, H. E., 1956, Der Wattenboden und das Leben im Wattenboden: Natur und Volk, Bd. 86, heft 9, p. 268–284, figs. 1–14.

RICHTER, RUDOLPH, 1931, Tierwelt und umwelt im Hunsrückschiefe zur Entstehung eines schwartzen Schlammsteins: Senckenbergiana, Bd. 13, no. 5/6, p. 299–342, figs. 1–16.

ROE, ANNE, & SIMPSON, G. G., editors, 1958, Behavior and evolution: Yale Univ. Press, 557 p.

ROMER, A. S., 1945, Vertebrate paleontology (2d ed.): Univ. Chicago Press, 687 p.

——, 1955, Fish origins—fresh or salt water?: Deep-Sea Research, v. 3, supp., Papers in marine biology and oceanography, p. 261–280.

ROMER, A. S., & OLSON, E. C., 1954, Aestivation in a Permian lungfish: Breviora, Mus. Comp. Zoology, no. 30, p. 1–8.

RUBEY, W. W., 1951, Geological history of sea water: Geol. Soc. America Bull., v. 62, no. 9, p. 1111–1147, figs.

RÜCKLIN, HANS, 1954, Die Grenzschichten Buntsanstein-Muschelkalk in Saarland—ein fossiles Watt: Jahresber. Mitt. Oberrhein. Geol., Ver., 35 (1953), p. 26–42, pl. 1.

RUKHIN, L. B., 1957, Paleoclimatology and biostratigraphy (in Russian): USSR Pal. Soc., 1st sess., Problems of Paleobiogeography and Biostratigraphy, p. 25–41, figs. 1–2. (Рухин, Л.Ъ., 1957, Климаты Прошлого и биостратиграфия: Всесоюзное Палеонтологическое Общество, Труци I Сессии, 1955, Москва; Вопросы Палеобиогеографии и Ъиостратиграфии, стр. 25–41, Рис. 1–2).

RUSSELL, R. D., editor, 1951, Turbidity currents and the transportation of coarse sediments to deep water: Soc. Econ. Paleontologists Mineralogists Spec. Pub. 2, 107 p.

RUTTNER, FRANZ, 1953, Fundamentals of limnology; translated from the German by D. G. Frey and F. E. J. Fry: Univ. Toronto Press, 242 p.

SCHATZ, ALBERT, 1957, Some biochemical and physiological considerations regarding the extinction of the dinosaurs: Pennsylvania Acad. Sci. Proc., v. 31, p. 26–36.

SCHINDEWOLF, O. H., 1955, Über die möglichen Ursachen der grossen erdgeschichtlichen Faunenschnitte: Neue Jahrb. Geol. und Paläont., Jahrg. 1954, p. 457–465.

SCHINDEWOLF, O. H., & SEILACHER, ADOLF, 1955, Beiträge zur Kenntnis des Kambriums in der Salt Range (Pakistan): Akad. Wiss. Literatur Mainz, Abh. Math.-Naturw. Kl., Jahrg. 1955, no. 10, 190 p. (p. 261–456).

SCHMIDT, K. P., 1955, Animal Geography: A century of progress in the natural sciences—1853–1953: Calif. Acad. Sci., p. 767–794, figs. 1–5.

SCHWARZBACH, MARTIN, 1950, Das Klima der Vorzeit, Eine Einführung in die Paläoklimatologie: Stuttgart, F. Enke, p. 1–211, figs. 1–70.

SEIBOLD, EUGEN, 1958, Jahreslagen in Sedimenten der mittleren Adria: Geol Rundschau, Bd. 47, heft 1, p. 100–117, figs. 1–5.

SEILACHER, ADOLF, 1953, Über die Methoden der Palichnologie. Studien zur Palichnologie, No. 1; Die fossilen Ruhespuren (Cubichnia), No. 2: Neues Jahrb. Geol. und Paläont., Abh., Bd. 96, p. 421–452; Bd. 98, p. 87–124.

——, 1954, Die geologische Bedeutung fossilen Lebensspüren: Geol. Gesell, Zeitschr., Bd. 105, p. 214–227, figs. 1–3, pls. 7,8.

——, 1957, An-aktualistisches Wattenmeer?: Paläont. Zeitschr., Bd. 31, nr. 3/4, p. 198–206, pl. 22–23.

SENN, ALFRED, 1940, Paleogene of Barbados and its bearing on history and structure of Antillean-Caribbean region: Am. Assoc. Petroleum Geologists Bull., v. 24, no. 9, p. 1548–1610, figs. 1–4.

SEWARD, A. C., 1931, Plant life through the ages: New York, Macmillan Co., 601 p.

SHAPLEY, HARLOW, editor, 1953, Climatic change: Cambridge, Mass., Harvard Univ. Press, 318 p.

SHOTWELL, J. A., 1955, An approach to the paleoecology of mammals: Ecology, v. 36, no. 2, p. 327–337, figs. 1–4.

SIEVER, RAYMOND, 1957, The silica budget in the sedimentary cycle: Am. Mineralogist, v. 42, p. 821–841, figs. 1, 2.

SIMPSON, G. G., 1953, Evolution and geography: Oregon State System of Higher Education, Condon Lectures, 64 p.

SIMPSON, SCOTT, 1955, On the trace-fossil *Chondrites:* Geol. Soc. London Quart. Jour., v. 112, p. 475–500, figs. 1,2, pls. 21–24.

SOLLE, GERHARD, 1956, Die Watt-Fauna der unteren Klerfer Schichten vom Greimerath (Unter-Devon, Südost-Eifel); Zugleich ein Beitrag zum unterdevonischen Mollusken-Fauna: Hess. Landesamt für Bodenf., Abh., H. 17, 47 p.

SPJELDNAES, NILS, 1958, Ordovician climatic zones: Geol. Soc. America Bull., v. 69, no. 12, p. 1647.

STECHOW, E., 1954, Zur Frage nach der Ursache des grossen Sterbens am Ende der Kreidezeit: Neues Jahrb. Geol. und Paläont., Monatshefte, 1954, p. 183–186.

STEHLI, F. G., 1957, Possible Permian climatic zonation and its implications: Am. Jour. Sci., v. 255, p. 607–618, figs. 1–5.

STEVANOVIĆ, P. M., 1951, Donji Pliocen Srbije i susednih oblasti; geološko-paleontološka studija kaspi-brakičnih facija i produktivnih terena pontiskog kata: Srpska Akad. Nauka, Posebna Izdanja, v. 187, p. 1–361.

STOMMEL, HENRY, 1957, A survey of ocean current theory: Deep-Sea Research, v 4, p. 149.

STRAATEN, L. M. J. U. VAN, 1951, Longitudinal ripple marks in mud and sand: Jour. Sed. Petrology, v. 21, p. 47–54, figs. 1–5B.

——, 1954, Sedimentology of Recent tidal flat deposits and the Psammites du Condroz (Devonian): Geol. en Mijnbouw (n. ser.), Jaarg. 16, p. 25–27, figs. 1–15, pls. 1,2.

STRAATEN, L. M. J. U. VAN, & KUENEN, PH. H., 1957, Accumulation of fine-grained sediments in the Dutch Wadden Sea: Geol. en Mijnbouw (n. ser.), Jaarg. 19, p. 329–354, figs. 1–19.

——, 1958, Tidal action as a cause of clay accumulation: Jour. Sed. Petrology, v. 28, no. 4, p. 406–413, figs. 1–4.

STRAKHOV, N. M., 1947, Iron ore facies and their analogs during geologic time (in Russian): Akad. Nauk Soyuza SSR, Inst. Geol. Nauk, Trudy, v. 73, geol. ser. no. 22, 267 p. (Страхов, Н. М., 1947, Железорудные Фачии и их Аналоги в Истории Земли: Акац. Наук Союза С.С.Р., Трупы Инст. Геол. Наук, 73, Геол. Сер. 22, 267 стр.)

SUJKOWSKI, ZB. L., 1958, Diagenesis: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 11, p. 2692–2717.

SVERDRUP, H. V., JOHNSON, M. W., & FLEMING, R. H., 1942, The oceans: New York, Prentice-Hall, Inc., 1087 p.

TAYLOR, D. W., 1954, Nonmarine mollusks from Barstow formation of southern California: U. S. Geol. Survey Prof. Paper 254-C, p. 67–80.

TEICHERT, CURT, Cold- and deep-water coral banks: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 5, p. 1064–1082, 3 figs.

TERMIER, HENRI & TERMIER, GENEVIEVE, 1959, Evolution et palécgéographie: Paris, Albin Michel, 254 p.

TERZAGHI, KARL, 1956, Varieties of submarine slope failures: Harvard Soil Mechanics Ser. No. 52, Proc. 8th Texas Conf. Soil Mechanics and Found. Engineering, 41 p.

THODE, H. G., MACNAMARA, J., & FLEMING, W. H., 1953, Sulphur isotope fractionation in nature and geological and biological time scales: Geochim. et Cosmochim. Acta, v. 3, p. 235–243, figs. 1–3.

THOMPSON, J. B., JR., 1955, The thermodynamic basis for the mineral facies concept: Am. Jour. Sci., v. 253, p. 65–103, figs. 1–3.

THOMPSON, T. G., & CHOW, T. J., 1955, The strontium-calcium atom ratio in calcium-carbonate secreting marine organisms: Deep-Sea Research suppl. v. 3, Papers in marine biology and oceanography, p. 20–39.

THORSON, GUNNAR, 1950, Reproduction and larval ecology of marine bottom invertebrates: Biol. Reviews, v. 25, no. 1, p. 1–45, figs. 1–6.

TUREKIAN, K. K., & WAAGÉ, K. M., 1958, Geochemistry of the Fox Hills formation, South Dakota: Geol. Soc. America Bull., v. 69, no. 12, p. 1655.

VAUGHAN, T. W., 1940, Ecology of modern marine organisms with reference to paleogeography: Geol. Soc. America Bull., v. 51, p. 433–468, figs. 1–8.

——, & WELLS, J. W., 1943, Revision of the suborders, families, and genera of the Scleractinia: Geol. Soc. America, Spec. Paper no. 44, 363 p.

VERRILL, A. E., 1874, Report upon the invertebrate animals of Vineyard Sound and the adjacent waters, with an account of the physical characters of the region: U. S. Fish Comm., 1st Ann. Rept., 1871–1872, 478 p., pls. 1–38.

VINOGRADOV, A. P., translated from the Russian by Efron, Julia, and Setlow, Jane K., 1953, The elementary chemical composition of marine organisms: Yale Univ., Sears Found. Marine Research, 647 p.

VON ARX, W. S., 1957, An experimental approach to problems in physical oceanography, p. 1–28, *in* Ahrens, L. H. (ed.), et al., Physics and chemistry of the earth: New York-London-Paris, Pergamon Press, v. 2, 259 p.

WALTHER, JOHANNES, 1893, 1894, Einleitung in die Geologie als historische Wissenschaft. Theil I, Bionomie des Meeres; Theil II, Lebensweise der Meerestiere: 2 vols., 531 p.

WENZ, WILHELM, 1942–1946, Zur Kenntnis der Fossilen Land- und Süsswassermollusken Venetiens: Univ. Padova, Ist. Geol., Mem. v. 14, no. 6, 51 p.

WETZEL, OTTO, 1933, Die in organischer Substanz erhaltenen Mikrofossilien des baltischen

Kreide-Feuersteins mit einem sedimentpetrographischen und stratigraphischen Anhang: Palaeontographica, Bd. 77, p. 141–188, figs. 1–10; Bd. 78, p. 1–110, figs. 11–15, pls. 1–7.

WHITE, W. S., & WRIGHT, J. C., 1954, The White Pine copper deposit, Ontonagon County, Michigan: Econ. Geology, v. 49, no. 7, p. 675–716, figs. 1–11.

WILSER, J. L., 1931, Lichtreaktionen in der fossilen Tierwelt: Berlin, Gebrüder Borntraeger, 192 p.

WOODRING, W. P., 1928, Miocene mollusks from Bowden, Jamaica: Part II, Gastropods and discussion of results: Carnegie Inst. Washington Pub. 385, 564 p.

——, 1954, Conference on Biochemistry, paleoecology, and evolution: Natl. Acad. Sci. Proc., v. 40, no. 3, p. 219–224.

WOODRING, W. P., BRAMLETTE, M. N., & KEW, W. S. W., 1946, Geology and paleontology of Palos Verdes Hills, California: U. S. Geol. Survey Prof. Paper 207, 145 p.

WRIGHT, C. S., & PRIESTLEY, R. E., 1922, Geological climates of the Antarctic: British (*Terra Nova*) Antarctic Exped., 1910–1913, Glaciology, p. 418–470.

YEN, TENG-CHIEN, 1947, Distribution of fossil fresh-water mollusks: Geol. Soc. America Bull., v. 58, p. 293–298.

——, 1951, Fossil fresh-water mollusks and ecological interpretations: Geol. Soc. America Bull., v. 62, p. 1375–1380.

YOUNG, R. S., 1956, Cobalt in biology and biochemistry: Science Progress, v. 41, no. 173, p. 16–37.

——, 1957, The geochemistry of cobalt: Geoch. et Cosm. Acta, v. 13, p. 28–41.

ZALESSKY, M. D., 1938, Sur les zones climatiques de la terre au Carbonifère et au Permien: Pub. Lab. Paleont., Moscow Univ., Problems of Paleontology, v. 4, p. 333–362, illust. [Russian p. 333–347; French p. 347–362.]

ZOBELL, C. E., 1946, Studies on redox potential of marine sediments: am. Assoc. Petroleum Geologists Bull., v. 30, no. 4, p. 477–513, figs. 1–5.

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 963–968, 2 TEXT-FIGS., SEPTEMBER 1959

PALEONTOLOGICAL NOTES

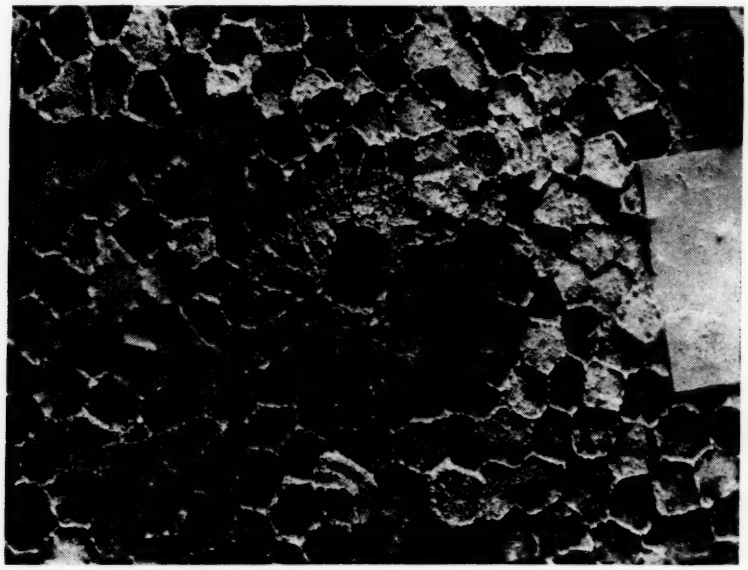
REEXAMINATION OF *PALAEOCREUSIA DEVONICA* CLARKE

HARRY S. LADD
U. S. Geological Survey, Washington 25, D. C.

In 1888 John M. Clarke described *Palaeocreusia devonica* from a specimen attached to a colony of *Favosites hemisphericus*. Clarke believed the species to be a Devonian representative of barnacles such as those included in the Recent genera *Creusia* and *Pyrgoma* that are epizoic on reef corals. Clarke was not able to determine distinctive generic features but he proposed the name *Palaeocreusia* tentatively in the expectation that such characters would eventually be found. Actually, after 70 years, Clarke's type remains the only known specimen though large collections of Devonian corals from the area where the type was collected have been examined. A reexamination of the type indicates clearly that the shell is not a cirripede; it is probably a limpet that became lodged on the surface of the coral and was overgrown.

I am indebted to Clinton F. Kilfoyle of the New York State Museum for the loan of the type and to Fred T. Hall of the Buffalo Society of Natural Sciences and Irving G. Riemann of the University of Michigan for reports on coral collections. Publication is authorized by the Director, U. S. Geological Survey.

As a possible ancestor of a specialized type of barnacle that is known to be associated with reef corals round the world today and in late Tertiary and Pleistocene times the Devonian fossil has been cited a number of times. In the 1900 edition of the Zittel-Eastman Text-book of Paleontology (p. 652), in which Clarke was a collaborator, it was diagnosed and figured without qualification and, on the strength of this reference, *Pyrgoma* (*Creusia*) was also cited from the Devonian. In the 1913 edition of the same text (p. 747) the brief diagnosis was preceded by the words "Affinities doubtful"



TEXT-FIG. 1—*Palaeocreusia devonica* Clarke, type, No. 4606 New York State Museum. Shell is on surface of *Favosites hemisphericus* from Onondaga limestone, Leroy, New York.

and the reference of *Pyrgoma* (*Creusia*) to the Devonian was followed by a question mark. In 1921, in his volume on Organic Dependence and Disease, Clarke republished his original figures and stated that the barnacle was buried in the coral "partly by burrowing and partly by solution."

On at least 4 occasions from 1915 to 1928 the late Thomas H. Withers raised questions about the affinities of *Palaeocreusia*. Withers did not have an opportunity to examine the specimen but concluded that it probably was not a cirripede at all. He was the first to suggest that it might be a limpet (Withers, 1915, 1924, 1926, 1928).

Recently, in connection with a study of Tertiary and younger Pyrgomas, I borrowed the type of *Palaeocreusia devonica* (text-fig. 1). By slightly extending the excavation beneath the shell started by Clarke it was found that the honeycomb pattern of the coral extended inward at least to a point below the edge of the central aperture. The depth of the "basis" in this area is only 4 mm. and the cavity as shown in Clarke's somewhat imaginative drawing is thus greatly reduced. The exact shape of the cavity cannot be made out clearly but in it there are traces of structures that suggest the vertical walls of the coral. In any event, it seems abundantly clear that the *Palaeocreusia* is not a cirripede of the *Pyrgoma* type. The cap-like shell is most probably a limpet, possibly belonging to the Fissurellidae as suggested by Withers (1915, p. 116). The silicified shell is not well enough preserved for generic or specific identification. The central opening appears eroded and the part remaining could well be the remnant of an acmaeid or patellid limpet; limpets of both types have been reported from rocks as old as Silurian. The faint radial markings are similar to those of limpets and the submarginal furrow may merely reflect an interruption of growth. Clarke believed that this furrow may have marked the contact between basis and capitulum but, as Withers pointed out (1915, p. 116), these two parts, in Recent forms, meet at the extreme margin of the shell. The low walls of the favosite that are continued across the shell indicate, as Clarke recognized, that the coral once covered the shell. Such occurrences are by no means uncommon among true Pyrgomas, both living and fossil.

REFERENCES

CLARKE, JOHN M., 1888, Descriptions of trilobites and other Crustacea, Geol. Surv. New York, Paleontology, v. 7, p. 210–211, pl. 36, figs. 24–26.

——, 1921, Organic dependence and disease, New York State Mus., Bull, 221,222, p. 61–62.

WITHERS, THOMAS H., 1915, Some Palaeozoic fossils referred to the Cirripedia, Geol. Mag., dec. 6, v. 2, no. 3, p. 114–116.

——, 1924, The phylogeny of the Cirripedia, Annals and Mag. Nat. Hist., v. 14, no. 81, p. 322–324.

——, 1926, Catalogue of the Machaeridia, Brit. Mus. (Nat. Hist.), p. 1.

——, 1928, Catalogue of fossil Cirripedia, Brit. Mus. (Nat. Hist.), v. 1, p. 19–20.

ZITTEL, KARL A. VON & EASTMAN, CHARLES R., 1900, Text-book of Palaeontology, v. 1, p. 652; 2nd ed., 1913, p. 747.

LEIORHYNCHUS OR *NUDIROSTRA*

PAUL SARTENAER
Institut royal des Sciences naturelles de Belgique

In 1951, H. M. MUIR-WOOD and G. A. COOPER considered that *Liorhynchus* RUDOLPHI, K. A., 1801 (*Vermes*) and *Leiorhynchus* HALL, J., 1860 (*Brachiopoda*) were homonyms. Consequently, they substituted the name *Nudirostra* for the junior homonym, in application of section 1a of Article 34 of the "Règles." This section 1a, proposed and adopted in 1935, in Lisbon, at the 12th International Congress of Zoology, under the Opinion 147, came into force in 1943.

Already in 1941 (p. 41), HERTA SCHMIDT had considered *Liorhynchus* and *Leiorhynchus* to be homonyms, disagreeing with C. SCHUCHERT and C. M. LEVENE (1929), who

said *Leiorhynchus* and *Liorhynchus* did not conflict. But, in 1929, the latter authors were right in their opinion.

Application of section 1a depends, however, on the condition that two generic names have the same origin and meaning. In spite of the fact that it seems highly probable that the same Greek adjective, λεῖος (=smooth, polished, even, flattened), enters into the composition of *Leiorhynchus* and of *Liorhynchus*, since J. HALL, unlike RUDOLPHI, did not give the derivation of the name he had chosen, there exists no evidence of it. Therefore H. M. MUIR-WOOD and G. A. COOPER were not authorized to consider the two names as homonyms. So *Leiorhynchus* remains a valid name and authors, myself included, who, since 1951, used *Nudirostra*, now an objective synonym, were wrong.

Moreover, the Recommendation 41 taken at the 13th International Congress of Zoology in 1948, in Paris, and published in 1950—but, of course, still without force of law in 1951[1]—restricted the application of the Opinion 147 to generic names which were based upon the same Latin or latinised word, upon the same modern patronymic or upon the same geographical or topographical term. This is obviously not the case for *Leiorhynchus* and *Liorhynchus*.

It might be added, although the case here discussed is closed, that the revised "Règles" will take care of cases of the kind here examined. As a matter of fact, the Colloquium on Zoological Nomenclature of Copenhagen (1953) has recommended: "A generic name is not to be treated as a homonym of another such name if it differs from it in spelling by even one letter." The recommendation, approved by the competent groups "will not formally come into operation until the first day of January in the calendar year following that in which the revised 'Règles' are published." The publication in 1957 and 1958, respectively of the drafts of the English and French texts of the revised "Règles" indicates that the publication of the final text is nearing.

[1] It will never have force of law according to Decision 152 of the Copenhagen Decisions on Zoological Nomenclature (1953), which suppressed the restriction.

LITERATURE CITED

COOPER, G. A., & MUIR-WOOD, H. M., 1951, Brachiopod homonyms: Jour. Wash. Acad. Sci., v. 41, no. 6, p. 195–196.

HALL, JAMES, 1860, Contributions to palaeontology 1858 and 1859: 13th Ann. Rept. Regents Univ. Sta. New York, p. 55–125.

LEVENE, C. M., & SCHUCHERT, CHARLES, 1929, *Brachiopoda* (Generum and Genotyporum Index and Bibliographia), *in* Fossilium Catalogus I: Animalia, Pars 42.

RUDOLPHI, K. A., 1801, Beobachtungen über die Eingeweidewürmer, *in* Wiedeman, C. R. W., Archiv. für Zoologie und Zootomie, Band 2, Stück 1, p. 1–65.

SCHMIDT, HERTA, 1941, Die mitteldevonischen Rhynchonelliden der Eifel: Abh. Senck. Naturf. Gesell., no. 459.

Appendices: Corrigenda; Indexes, 1955: Opinions and Declarations rendered by the International Commission on Zoological Nomenclature, v. 2, Pt. 59, p. 719–768.

Arrangements made by the International Trust for Zoological Nomenclature for the publication of Professor J. Chester BRADLEY's Draft of the English text of the *Règles* as amended by the International Congresses of Zoology held in Paris and Copenhagen in 1948 and 1953 respectively. Part 1 of the Draft of the revised English text of the *Règles*, 1957: Bull. Zool. Nomencl., v. 14, Sextuple—Pt. 1/6, p. 1–190.

Copenhagen decisions on zoological nomenclature, Additions to, and modifications of, the Règles Internationales de la Nomenclature Zoologique approved and adopted by the fourteenth International Congress of Zoology, 1953, London.

Concluding Portion (Parts 2 and 3) of the Draft of the revised English text of the *Règles*, 1957: Bull. Zool. Nomencl., v. 14, Triple—Pt. 7/9, p. 191–286.

Concluding Portion (Parts 2 and 3) of the Draft of the revised French text of the *Règles*, 1958: Bull. Zool. Nomencl., v. 14, Triple—Pt. 17/19, p. 539–634.

Opinion 147. On the principles to be observed in interpreting Article 34 of the International Code in relation to the rejection, as homonyms, of generic and subgeneric names of the same origin and meaning as names previously published, 1943: Opinions and Declarations rendered by the International Commission on Zoological Nomenclature, v. 2, Sec. A, Pt. 14, p. 123–132.

Part 1 of the French text of the revised Draft of the "Règles," 1958: Bull. Zool. Nomencl., v. 14, Quintuple—Pt. 12/16, p. 371–538.

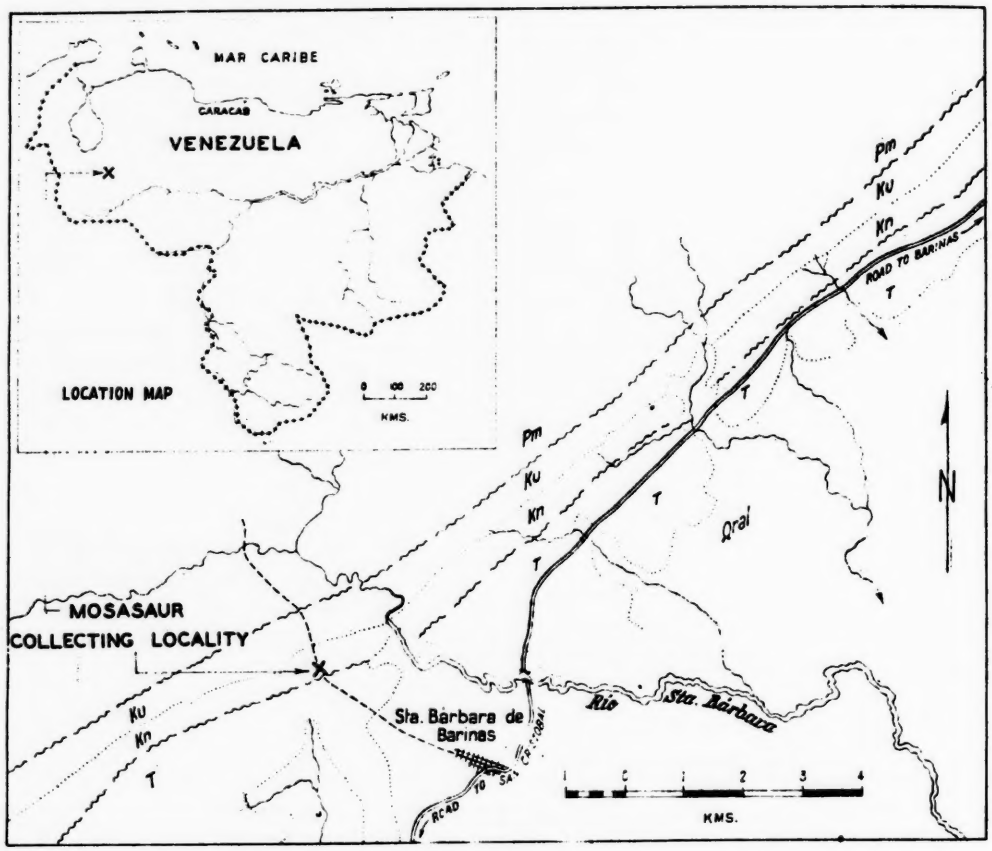
Recommendation 41, 1950: Bull. Zool. Nomencl., v. 4, Pts. 7/9, p. 159–254.

FIRST RECORD OF MOSASAUR FROM THE CRETACEOUS OF SANTA BARBARA DE BARINAS, VENEZUELA

G. R. PIERCE AND S. P. WELLES

In 1953 six badly eroded fragments of mosasaur(s) were collected from the Navay formation of Upper Cretaceous age near Santa Barbara de Barinas, Venezuela, and constitute the first occurrence of mosasaur(s) in Venezuela. The collection has been identified by S. P. Welles, co-author, of the University of California, Museum of Paleontology.

The lithologic peculiarities of the Upper Cretaceous Navay formation of the southwestern Andean region of Venezuela have



LEGEND

ALLUVIUM	Qral	URIBANTE FORMATION	Ku
TERTIARY SEDIMENTS	T	PALEOZOIC- METAMORPHIC	Pm
NAVAY FORMATION	Kn	TRAIL / ROAD	

TEXT-FIG. 1—Mosasaur collecting locality, Santa Barbara de Barinas, Venezuela.

been noted by numerous geologists—Christ (1927, p. 404), Kehrer (1938, p. 49), Liddle (1946, p. 258) and several geologists doing exploration work for various private companies in this part of Venezuela. The Navay formation is composed of dark gray to black carbonaceous shales, siliceous shales to highly porous, tripolitic cherts and a few hard non-porous cherts. Lenticular masses of light gray limestones have been noted. A few medium- to coarse-grained sandstones, some porous and cemented with white chert, others, tightly cemented by calcite, have been mapped. These sandstones are generally fossiliferous. While various facies are gradational one into another the dominant lithology is siliceous shale. These shales are intermediate between the normal dark gray shales and the cherts. They are generally light gray to tan to white in color, brittle, of low specific gravity and considerably weathered. They are composed of clays, clastic and non-clastic, cryptocrystalline to microcrystalline quartz and numerous fluorapatite fossil fragments. In fact, in many exposures near Santa Barbara de Barinas the shales have been described as "bone beds"—of fish vertebrae, scales, etc. Scales of a herring-like fish of the family Clupeidae are the most common elements of the fauna. It is from these very fossiliferous siliceous shales near Santa Barbara de Barinas that the mosasaur(s) specimens were collected (see text-fig. 1).

The following specimens have been identified:

1. Posterior dorsal vertebra of mosasar.
2. Indeterminate, not vertebra; could be part of pectrum or pelvis or propodial of mosasaur.
3. Vertebra—could be anterior caudal of same individual.
4. Indeterminate vertebral centrum.
5. Probably a fragment of a vertebral centrum near No. 1.
6. Indeterminate. Not recognized as mosasaur, but if so might be part of pelvis.

In general, the mosasaur is much larger than *Clidastes* or *Platecarpus* and is about the size of *Tylosaurus* of the Mid-Continent and the Gulf Coast beds or *Plesiotylosaurus* from California. The weathered dorsal centrum is 90 mm. long from anterior concavity to the posterior end, not including the convex ball. A corresponding centrum of *Liodon* sp. figured by Cope (1875, pl. 34) measures 86 mm. Because of extreme weathering and the fragmentary nature of the specimens, exact identification is not possible.

Age determination is more positive than identification as these giant mosasaurs are restricted to the Upper Cretaceous. The Mid-Continent forms are Campanian or later, while the Californian forms are Maestrichtian.

Other fossils from the Navay formation include foraminifera, gastropods, pelecypods, ammonites and numerous examples of delicately preserved small crabs which are completely flattened along bedding planes. The plant spore *Punctati-sporites* has been identified from many shale samples of the Navay formation. The age of the formation is unquestionably Upper Cretaceous.

BIBLIOGRAPHY

CHRIST, PETER, 1927, La Coupe Geologique le long du chemin de Mucuchachi a Santa Barbara dans les Andes Vénézuélinnes. Eclog. Géol. Helv.

COPE, E. D., 1875, The vertebrata of the Cretaceous formations of the west. Rept. U. S. Geol. Surv. Territories, v. 2, p. iv+1–301, 9 figs., 57 pls.

KEHRER, L., 1938, Some Observations on the Stratigraphy in the States of Táchira and Mérida, S. W. Venezuela. Bol. Geol. y Minería, p. 44–54.

LIDDLE, R. A., 1946, The Geology of Venezuela and Trinidad. Paleontological Res. Inst., Ithaca, New York.

THE REPORTED OCCURRENCE OF *REITHRODONTOMYS* IN THE PLEISTOCENE OF FLORIDA

ROBERT S. BADER
Department of Zoology, University of Illinois, Urbana

A small rodent mandible from Stratum No. 2 of the Pleistocene beds at Vero Beach, Florida was referred to *Reithrodontomys humulis* by Simpson (1930). Although knowledge of the microvertebrates of the Florida Pleistocene has increased considerably in the past two decades, no subsequent finds referable to the genus have been reported. Recent reexamination of the specimen (Fla. Geol. Surv. No. V-1539) indicates that it should be assigned to *Peromyscus polionotus* rather than *R. humulis*.

Although the mandible itself is fragmentary, the presence of all three, slightly worn, molars facilitates specific identification. The Vero specimen may be readily distinguished from *R. humulis* by the greater relative size and S-shaped configuration of the M_3 and by the absence of the labial cingulum and its cusplets on M_{1-2}. The dental pattern is much closer to that of *R. fulvescens* which also possesses an S-shaped M_3 and lacks the labial cingulum. The latter is, however, separable from the Florida specimen on the following bases: in M_1 the anteroconid is separated from the major cusps immediately posterior to it, the protoconid and metaconid, by a narrow median isthmus; in M_{1-2} a ridge extends across the mouth of the first primary fold on the lingual border of the tooth; in M_3 there is a greater labial extension of the protoconid relative to the hypoconid. On the other hand, the dental pattern of the fossil is quite similar in all major aspects to that of *P. polionotus*. Its most unique feature is a very feebly developed anterolophid on the M_3. With respect to size, it falls within the observed range, although somewhat below the mean, of 9 dental measurements of a large sample ($N = 52$) of recent *polionotus* from Florida.

The list of extant terrestrial mammalian genera of Florida which have not been found in the Pleistocene of the state must, at least for the present, be emended to include *Reithrodontomys*, in addition to *Sorex* and *Glaucomys*. The absence of *R. humulis* from the Florida Pleistocene is in accordance with the conclusion of Hooper (1943) that this southeastern form has been extending its range within historic times.

The dental terminology follows that of Hooper (1952). The loan of the Vero specimen by Mr. S. J. Olsen of the Florida Geological Survey was very much appreciated. This report is a part of a study of the Pleistocene rodents of Florida which is supported by Grant no. G-6262 of the National Science Foundation.

REFERENCES CITED

HOOPER, E. T., 1943, Geographic variation in harvest mice of the species *Reithrodontomys humulis:* Occ. Papers Mus. Zool. Univ. Mich., no. 477, p. 1–19.

——, 1952, A systematic review of the harvest mice (genus *Reithrodontomys*) of Latin America: Misc. Publ. Mus. Zool. Univ. Mich., no. 77, p. 1–255.

SIMPSON, G. G., 1930, Additions to the Pleistocene of Florida: Am. Mus. Novitates, no. 406, p. 1–14.

JOURNAL OF PALEONTOLOGY, V. 33, NO. 5, P. 969–970, SEPTEMBER 1959

NOMENCLATURAL NOTE

TEXTULARIA YORKTOWNENSIS, NEW NAME

JAMES D. McLEAN, JR.
Alexandria, Virginia

Dr. Hans E. Thalmann, in a personal communication, has advised me that my subspecies *Textularia pseudobliqua* subsp. *aspera* has been preoccupied by *Textularia aspera* Ehrenberg, 1838, Abhandl, k. Akad. Wiss., Berlin, 134, iv, v, gamma. It has also been preoccupied by *T. aspera* Terquem, 1882, and *T. aspera* Brady, 1882, according to Thalmann.

For this reason, I propose the name *Textularia yorktownensis* for *Textularia pseudobliqua* subsp. *aspera* McLean (non Ehrenberg), 1956, Bull. Amer. Pal., vol. XXXVI, No. 160, p. 320, pl. 36, figs. 8,14.

SOCIETY RECORDS AND ACTIVITIES

PACIFIC COAST SECTION OF THE PALEONTOLOGICAL SOCIETY

PROCEEDINGS OF THE FORTY-SIXTH ANNUAL MEETING HELD AT THE UNIVERSITY OF ARIZONA, TUCSON, ARIZONA

APRIL 3–4, 1959

R. L. LANGENHEIM, JR. *Secretary*

The Forty-sixth Annual Meeting of the Pacific Coast Section of the Paleontological Society was held at the University of Arizona, Tucson, Arizona on Friday and Saturday, April 3–4, 1959.

LUNCHEON AND BUSINESS MEETING

A luncheon and business meeting was held at noon Friday, April 3, 1959 at the University of Arizona Student Union. Twenty-four members and guests were in attendance. In the absence of Chairman V. S. Mallory, Vice-Chairman John F. Lance presided at the luncheon. Past Chairman E. M. Baldwin, however, presided at the business meeting as Vice-Chairman Lance was called away on business pertaining to the general meetings.

The minutes of the last meeting were read and approved.

The following slate of officers for the year 1958–59 was presented by the chairman of the nominating committee, J. W. Durham.

Chairman

R. L. LANGENHEIM, JR.—University of California, Berkeley, California

Vice-Chairman

H. J. BISSELL—Brigham Young University, Provo, Utah

Secretary

D. L. JONES—U. S. Geological Survey, Menlo Park, California

Councilor

J. F. LANCE—University of Arizona, Tucson, Arizona

W. J. Youngquist moved nominations closed, O. L. Bandy seconded the motion and the motion was passed unanimously by members of the Section present.

R. L. Langenheim, Jr. presented an informal report of the proceedings of the Council meeting held in St. Louis. An informal discussion of problems of financing publication and of possible changes in the council of the society followed.

It was moved by J. W. Durham that the Section express the thanks of its members for the arrangements made by the Department of Geology of the University of Arizona and the Arizona Geological Society for the meeting and field trips. The motion was

seconded by G. D. Hanna and passed by acclamation.

There being no further business, the meeting adjourned at 1:00 P.M.

SCIENTIFIC SESSIONS

Saturday, April 4, 9:00 A.M.

PALEONTOLOGY

Room 110, Business and Public Administration Building Cochairmen: Roger Y. Anderson and Donald E. Savage

1. Jane Gray* and John L. Browning: Caytonialean microspores from the Jurassic and Cretaceous of Alaska (10 minutes)
2. Daniel I. Axelrod: Evidence for a tropical center of angiosperm evolution (15 minutes)
3. Wayne L. Fry: Fossil plants from the Canadian Archipelago (15 minutes)
4. Joseph Lintz, Jr.: Ultrasonics—Laboratory tool or toy? (5 minutes)
5. Wayne P. Jones: New species of phacopid trilobite (15 minutes)
6. J. Keith Rigby: Precambrian, Cambrian, Ordovician, and Silurian sponges in North America (10 minutes)
7. W. W. Wornardt, Jr.: Stratigraphy and paleontology of Brazer limestone in southernmost part of Lost River Range, Idaho (15 minutes)
8. Halsey W. Miller, Jr.: Invertebrate fauna of the Niobrara formation (Cretaceous) of Kansas (15 minutes)

Saturday, April 4, 1:30 P.M.

PALEONTOLOGY

Room 110, Business and Public Administration Building Cochairmen: Theodore Downs and Jane Gray

1. William A. Clemens: Type Lance formation and its mammal fauna (20 minutes)
2. J. Wyatt Durham and David L. Jones:* Some fossil occurrences bearing on the Franciscan problem in central California (20 minutes)
3. LouElla R. Saul: Upper Cretaceous faunal assemblages from Chico Creek, Butte County, California (15 minutes)
4. Orville L. Bandy: Geologic significance of coiling ratios in the foraminifer *Globigerina pachyderma* (Ehrenberg) (20 minutes)
5. York T. Mandra: Use of fossil silicoflagellates in paleogeography (10 minutes)
6. J. Wyatt Durham: *Scutellaster oregonensis* in the Pacific Coast Pliocene (15 minutes)
7. Thomas Clements: Chapala formation, Jalisco, Mexico (20 minutes)

* Speaker.

PROPOSED NEW MEMBERS

In accordance with Article 3, Chapter 1, of the By-Laws of the Paleontological Society, the names of new members approved by the Council are as follows:

AGER, DEREK VICTOR, Department of Geology, Imperial College of Science and Technology, London SW 7, England: Harold W. Scott, M. L. Thompson

BRENNER, GILBERT J., Department of Geology, Ihlseng Laboratory, Pennsylvania State University, State College, Pa.: Frank M. Swartz, Edward A. Stanley, Robert L. Ericson

DODDS, ROLAND KENNETH, 8617 Scoffins Street, Tigard, Oregon: Walter Youngquist, Ewart M. Baldwin

HORTON, RICHARD WILLIAM, 913 Jackson Street, Oshkosh, Wisconsin: Joseph G. Emielity, Elmer R. Nelson, Katherine G. Nelson

LEMONE, DAVID VONDENBURG, 909 Loma Linda Avenue, Farmington, New Mexico: John Thomas Sample, Jr., Rousseau H. Flower

MUMMA, MARTIN DALE, Department of Geology, Swallow Hall, University of Missouri, Columbia, Mo.: Raymond E. Peck, Harry B. Whittington

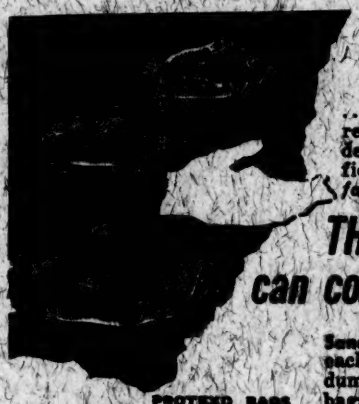
STANLEY, DONALD ALVORA, 1344 Alder Street, Eugene, Oregon: Walter Youngquist, Ewart M. Baldwin

WEST, RONALD ROBERT, c/o Marine Exploration Group, Shell Oil Company, P.O. Box 193, New Orleans 3, La.: John J. Gouty, Don L. Frizzell, A. C. Spreng

McLEAN PALEONTOLOGICAL LABORATORY

Card catalogues of fossils available by subscription, created on contract or by mutual agreement. Compilation and research facilities by contract. Training program for micropaleontologists offered.

James D. McLean, Jr., Box 916, Alexandria, Virginia, U.S.A.



...the sand sample that can't be identified when it reaches the lab—the sample that *could* influence decisions concerning future development of an entire field—the sample that is lost forever *because of a faulty container*...

THIS handful of sand can cost you thousands of dollars!

Sand samples are important. They cost at least $2.00 each to collect and process. Yet up to 25% are dumped uncut because of illegible tags or inferior bags. Lost is the investment in handling costs. Forever lost is valuable information. Stop such losses with HUBCO PROTEXO SAND SAMPLE BAGS.

We'd like to tell you the whole story behind HUBCO Protexo Bags. For more information, a sample and dealer's name *mail in the coupon*.

PROTEXO BAGS
- Strong
- Silt-proof
- Geologist-designed
- Highest Quality Cambric Cloth

MAGIC MARK TAGS
- Water-Insect-and Mildew-proof
- Guaranteed to keep even ordinary pencil markings legible.

HUBCO Protexo Bags were designed with the GEOLOGIST in mind.

HUTCHINSON BAG CORPORATION Dept. JP
P. O. Box 868, Hutchinson, Kansas

Name_____

Company_____

Street_____

City_____ State_____